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PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of

Docket No: Q63913

Rui ISHIYAMA

Appln. No.: 09/823,763

Group Art Unit: 2621

Confirmation No.: 9124

Examiner: Tom Y. LU

Filed: April 3, 2001

For: DEVICE, METHOD AND RECORD MEDIUM FOR IMAGE COMPARISON

SUBMISSION OF AFFIDAVIT UNDER 37 C.F.R. §1.131

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

Submitted herewith is a copy of an executed Affidavit Under 37 C.F.R. §1.131 signed by Rui Ishiyama executed on July 7, 2006. Submitted with the Affidavit are the following documents:

Document A: A specification that the inventor himself drafted

Document B: A Notification of employee's invention

Document C: A Request for patent application

Document D: A copy of the case history for the priority document

Document E: A verified English translation of the priority document

Respectfully submitted,

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Date: July 17, 2006

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Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

I, Rui Ishiyama, hereby declare and state as follows:

1. I am the inventor named in the above-captioned U.S. Application No. 09/823,763, filed April 3, 2001, which claims priority to Japanese Application No. 105399/2000.

2. At the time I invented the present invention, I was employed by NEC CORPORATION (hereinafter "NEC").

3. Prior to March 30, 2000, the U.S. Filing Date of U.S. Patent No. 6,956,569 to Roy et al., the invention as described and claimed in the above referenced application was completed at NEC, as evidenced by the following:

4. Prior to March 30, 2000, having earlier conceived the idea as set forth in the specification of the above referenced application, the present invention was formally submitted in the form of a specification as shown in Exhibit A, as written by the inventor, to the patent department NEC in the form of a Notification of employee's invention, as shown in Exhibit B.

In the ordinary course of business and in due time, the present invention was assigned Reference Number 335-09734, a copy of which is attached hereto.

5. Exhibit A is the 22-page specification, written by the inventor, along with an English translation of said specification. Exhibit A includes subject matter that supports at least claims 2, 4, 6-9, 13-15, 21-22, 24, 27-29, 33, 35, 37-40, 44-46, 52-53, 55, 58-60, 64, 66, 68-71, 75-77, 83-84, 86, 89-91, 93, 95-96 and 99. These claims of the present application are described at least in the following passages of the English translation document in Exhibit A (further support may also be found elsewhere in Exhibit A):

Claim 2 – Pages 34-39, FIGS. 1-5

Claim 4 – Pages 34-35

Claims 6-9 – Pages 36-38

Claims 13-15 - Page 36

Claim 21 – Pages 39-41, FIGS. 6 and 7

Claim 22 - Pages 20-21, 39, 41 (citing pages 30-34 and 37-38)

Claim 24 - Page 9

Claim 27 - Page 35

Claims 28-29 - Page 39

Claim 30 - Page 4

Claim 33 - Pages 34-39, FIGS. 1-5

Claim 35 - Pages 34-35

Claim 37-40 - Pages 36-38

Claim 44-46 - Page 36

Claim 52 - Pages 39-41, FIGS. 6 and 7

Claim 53 - Pages 20-21, 39, 41 (citing pages 30-34 and 37-38)

Claim 55 - Page 9

Claim 58 - Page 35

Claim 59-60 - Page 39

Claim 61 - Page 4

Claim 64 - Pages 34-39, FIGS. 1-5 and page 10

Claim 66 - Pages 34-35

Claim 68-71 - Pages 36-38

Claim 75-77 - Page 36

Claim 83 - Pages 39-41, FIGS. 6 and 7

Claim 84 - Pages 20-21, 39, 41 (citing pages 30-34 and 37-38)

Claim 86 - Page 9

Claim 89 - Page 35

Claim 90-91 - Page 39

Claim 92 - Page 4

Claim 93 - Page 4

Claim 94 - Page 4

Claim 95 - Page 35

Claim 96 - Page 39

Claim 97 - Page 4

Claim 98 - Page 4

Claim 99 - Page 4.

6. At the time the subject matter of the present application was invented, it was common practice at NEC to have its patent applications prepared and filed by persons not employed by NEC.

7. In the ordinary course of business and in due time, NEC sent a request to Mr. Takao Maruyama of MARUYAMA PATENT OFFICE of Tokyo, Japan requesting the preparation and filing of utility patent application with the Japan Patent Office. The requests were sent from Mr. Hirotaka Saitoh, Patent Section of the Research and Development Head Office of NEC to Mr. Takao Maruyama. A copy of the above request is attached as Exhibit C.

8. In the ordinary course of business and in due course, Maruyama Patent Office prepared a draft utility application, and forwarded the application to NEC for inventor's review and approval on March 28, 2000.

9. In the ordinary course of business and in due course, NEC reviewed and approved the draft application prepared by Maruyama Patent Office, and Japanese Patent Application 2000-105399 was filed on April 3, 2000.

10. In view of the foregoing, it is clear that I, the named inventor of the above-captioned application, invented the subject matter of the claims prior to the March 30, 2000 U.S. filing date of U.S. Patent No. 6,956,569.

AFFIDAVIT UNDER 37 CFR §1.131
U.S. APPLICATION NO. 09/823,763

I hereby declare further that all statements made herein are of my own knowledge and are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: July 7, 2006

Rui Ishiyama
Rui Ishiyama

書類名

明細書

発明の名称

画像照合方法、装置、および記憶媒体

特許請求の範囲

1. 照合を行うための各物体のデータをデータベースに 登録する登録過程において、

物体の3次元形状と、物体の表面の反射率を測定し、該3次元形状と反射率を記 憶しておき、

入力される画像に対して登録データとの照合を行う照合過程において、

ビデオカメラ等の撮像装置を用いて入力画像として2次元画像を撮影し、

あらかじめ与えておいた一定の位置姿勢にあって、様々な照明条件のもとでの 物体の画像である照明変動画像群を登録されている3次元形状と反射率データ を用いて生成し、

該照明変動画像群から入力画像に最も近い画像を求めて比較画像として生成し、

該比較画像と前記入力画像の類似度の評価値を計算し、該類似度の評価値に基 づいて、対象物体であるかどうかの確認、登録されているどの物体であるかの 検索、登録されている物体のうち似ている物体の検索、等の処理を行う

ことを特徴とする画像照合方法。

2. 請求項1 記載の画像照合方法において、前 記比較画像の生成が、

前記照明変動画像群で張られる画像空間である照明変動空間を生成し、該照明 変動空間内にあって前記入力画像に最も近い画像を比較画像として生成するも のである

ことを特徴とする画像照合方法。

3. 請求項2 記載の画像照合方法にお いて、前記照明変動空間の生成が、

前記照明変動画像群を主成分分析などの統計的解析を施すことにより、照明条 件により画像上に現れている変動要因の大部分を覆うような空間の基底ベクト ルを求めることで、照明変動空間を生成するものであり、

前記比較画像の生成が、

前記基底ベクトルと入力画像との間の相関を求め、該相関を元に基底ベクトル から入力画像に最も近い比較画像を生成し出力するものである

ことを特徴とする画像照合方法。

4. 請求項1 記載の画像照合方法において、

前記照明変動画像群の生成を、前記登録過程においてあらかじめ行っておき、 該照明変動画像群を記憶しておき、

前記照合過程における比較画像の生成において、該登録されている照明変動画 像群を利用するものである

ことを特徴とする画像照合方法。

5. 請求項2 記載の画像照合方法に おいて、前記照合過程における照明変動画像群の生成および照明変動空間の生 成を、

あらかじめ登録過程において行い該生成された照明変動空間を記憶しておき、 前記照合過程の比較画像生成において、該登録されている照明変動空間を利用 する

ことを特徴とする画像照合方法。

6. 請求項3 記載の画像照合方法 において、前記照合過程における照明変動画像群の生成および基底ベクトル群 の生成を、

あらかじめ登録過程において行い該生成された基底ベクトル群を記憶しておき、

前記照合過程の比較画像生成において、該登録されている基底ベクトル群を利 用する

ことを特徴とする画像照合方法。

7. 請求項1 から 請求項6 記載 の画像照合方法において、

前記あらかじめ与えられた一定の位置姿勢を用いるのではなく、前記入力画像 に写っている物体の位置姿勢のパラメタを別途入力する

ことを特徴とする画像照合方法

8. 請求項1 から 請求項6 記載の 画像照合方法において、

前記あらかじめ与えられた一定の位置姿勢を用いるのではなく、前記入力画像 に写っている物体の位置姿勢を前記登録されている3 次元形状と反射率を利用 して推定する

ことを特徴とする画像照合方法。

9. 請求項1 から 請求項8 記載 の画像照合方法において、前記登録過程において反射率を測定する代わりに、

適当な照明の下で画像情報を撮影し、以降の処理において反射率の代用として 前記画像情報を利用する

ことを特徴とする画像照合方法。

10. 請求項1 から 請求項8 に 記載の画像照合方法において、登録過程における反射率の測定が、

適当な数の異なる種類の照明条件の下での画像情報をテクスチャ画像群として 撮影する

ものであり、照合過程における照明変動画像群の生成において、

照明条件を変化させる代わりに前記テクスチャ画像群を利用する

ことを特徴とする画像照合方法。

11. 請求項1 から 請求項10 に記 載の画像照合方法において、登録過程において複数の照合対象となる物体の3 次元形状を測定する代わりに、

1つないし少数の3次元形状を測定するだけで、該1つの3次元形状ないし少数の 3次元形状の平均となる3次元形状1つを出力し、照合対象となる全ての物体の 形状は計測せず、

反射率の測定が、

照合対象となる全ての物体について反射率の計測もしくは一つないし複数の照 明条件の下での画像情報撮影を行うものであり、以降の処理においては3次元 形状として前記の平均の形状データだけを用いる

ことを特徴とする画像照合方法。

12. 請求項1 から 請求項11 まで に記載の画像照合方法において、

3次元形状の測定を行わず、別途図面等から3次元形状を入力しておく

ことを特徴とする画像照合方法。

13. 請求項1 から 請求項12 ま でに記載の画像照合方法において、前記反射率の測定を行わず、別途図面等から反 射率や色情報を入力しておくことを特徴とする画像照合方法。

14. 請求項1 から 請求項13 までに記 載の画像照合方法において、

登録過程において、 照合対象物体の特徴的な部位の位置情報を付与して登録する

こと特徴とする画像照合方法。

15. 請求項1 から 請求項14 までに記載の画像 照合方法において、自動車を前記照合対象とすることを特徴とする画像照合方 法。

16. 請求項1 から 請求項14 までに記載の画像 照合方法において、人間の顔を前記照合対象とすることを特徴とする画像照合 方法。

17. 照合を行うための各物体のデータをデータベース に登録する登録手段が、

データベースに登録する照合対象となる一つないし複数の物体の3次元形状を 測定し、該物体の3次元形状を出力する3次元形状測定手段と、

前記物体の3次元形状の各位置における表面の反射率を測定し、前記物体の反 射率として出力する反射率測定手段と、

前記3次元形状と反射率を入力とし、該3次元形状データと反射率を登録データ として記憶しておき、照合処理を行うために前記データを必要に応じて読み出 し出力するデータ記憶手段

を備え、入力される画像に対して登録データとの照合を行う照合手段が、

カメラなどの入力画像を撮影して出力する撮像手段と、

様々な照明条件を設定し照明条件群として出力する照明条件変化手段と、

あらかじめ与えておいた一定の位置姿勢と、データ記憶手段から出力される3 次元形状および反射率を入力とし、前記位置姿勢と同位置同姿勢にあって前記 照明条件群の照明条件の下での画像を照明変動画像群として生成する画像生成 手段と、

該照明変動画像群から前記入力画像に最も近い画像を求めて比較画像として出 力する照明条件推定手段と、

前記入力画像と前記比較画像を入力とし、該２つの画像の類似度の評価値を計 算し評価値を出力する画像比較手段と、

評価値を入力とし、該評価値に基づいて登録されている照合対象物体であ るかどうかの確認、または複数の登録されている物体のうちどの物体であるか の検索、または登録されている物体のうち見かけの似ている物体の検索、等の 処理を行い判定結果を出力する照合判定手段

を備えることを特徴とする、画像照合装置。

18. 請求項17 記載の画像照合装置において、 前記照合手段が、

前記照明変動画像群で張られる照明変動空間を生成し、照明変動空間を出力す る照明変動空間生成手段

を備え、前記照明条件推定手段が、

前記照明変動空間内にあって前記入力画像に最も近い画像を比較画像として生 成する照明条件推定手段

を備えることを特徴とする、画像照合装置。

19. 請求項18 記載の画像照合装置 において、前記照明変動空間生成手段が、

前記照明変動画像群を主成分分析などの統計的解析を施すことにより、照明条 件により画像上に現れている変動要因の大部分を覆うような空間の基底ベクト ル群を求めることで、照明変動空間を生成する

ものであり、前記照明条件推定手段が、

前記基底ベクトル群と前記入力画像との間の相関を求め、該相関を元に前記基 底ベクトル群から前記入力画像に最も近い画像である比較画像を生成する

ものであることを特徴とする画像照合装置。

20. 請求項17 記載の画像照合装置において、 照明補正手段が、

前記照明変動画像群を主成分分析などの統計的解析を施すことにより、照明条 件により画像上に現れている変動要因の大部分を覆うような空間の基底ベクト ルを求めることで、照明変動空間を生成し出力する照明変動空間生成手段を備 え、

照明条件推定手段が、

前記基底ベクトルと入力画像との間の相関を求め、該相関を元に基底ベクトル から入力画像に最も近い比較画像を生成し比較画像を出力するものである

ことを特徴とする画像照合装置。

21. 請求項17 に記載の画像照合装置に おいて、

前記照合手段には照明条件変化手段および画像生成手段がなく、

該照明条件変化手段および画像生成手段が登録手段に備わっており、記憶手段 が照明変動画像群を記憶しておき、

前記照合手段における照明条件推定手段が、前記登録されている照明変動画像 群を利用する

ことを特徴とする画像照合装置。

22. 請求項18 に記載の画像照合 装置において、

前記照合手段には照明条件変化手段および画像生成手段および照明変動空間生 成手段がなく、

該3つの手段が登録手段に備わっており、記憶手段が照明変動空間を記憶して おき、

前記照合手段における照明条件推定手段が、前記登録されている照明変動空間 を利用する

ことを特徴とする画像照合装置。

23. 請求項19 に記載の画像照 合装置において、

前記照合手段には照明条件変化手段および画像生成手段および照明変動空間生 成手段がなく、

該3つの手段が登録手段に備わっており、記憶手段が前記基底ベクトル群を記 憶しておき、

前記照合手段における照明条件推定手段が、前記登録されている基底ベクトル 群を利用する

ことを特徴とする画像照合装置。

24. 請求項17 から 請求項6 までに記載の画像照合装置において、

前記あらかじめ与えられた一定の位置姿勢を用いるのではなく、前記入力画像 に写っている物体の位置姿勢のパラメタを別途入力する位置姿勢入力手段

が追加され、照明補正手段が、

前記入力された位置姿勢を用いるものである

ことを特徴とする画像照合装置。

25. 請求項17 から 請求項6 まで に記載の画像照合装置において、

前記撮影手段から出力される入力画像を入力とし、該画像に写っている物体の 位置姿勢を推定し該位置姿勢を出力する位置姿勢推定手段

が追加され、照明補正手段が、

前記推定された位置姿勢を用いるものである

ことを特徴とする画像照合装置。

26. 請求項17 から 請求項24 ま でに記載の画像照合装置において、登録手段における反射率測定手段が、

適当な照明を設置して画像情報を撮影し該画像情報を反射率として出力する画 像撮影手段

であり、以降の手段において前記反射率の代用として前記複数の画像情報を利 用することを特徴とする画像照合装置。

27. 請求項17 から 請求項24 までに記載の画像照合装置において、登録手段における反射率測定手段が、

適当な数の異なる種類の照明条件を設定して画像情報を撮影し、該撮影した複 数の画像情報をテクスチャ画像として出力する画像撮影手段

であり、照合過程における照明条件変化手段がなく、

画像生成手段が、照明条件を変化させる代わりに前記テクスチャ画像群を利用 して画像を生成する

ことを特徴とする画像照合方法。

28. 請求項17 から 請求項24 までに記載の画像照合装置において、前記登録手段が、

1つないし少数の3次元形状を入力とし、該1つの3次元形状ないし少数の3次元 形状の平均となる3次元形状1つを出力する平均形状生成手段を備えており、

前記データ記憶手段が、前記生成された平均形状のみを記憶するものであり、

照合手段が前記平均形状を利用するものである

ことを特徴とする画像照合装置。

29. 請求項17 から 請求項27 までに記載の画像照合装置において、

前記3次元形状測定手段がなく、別途図面等から3次元形状を入力する

ことを特徴とする画像照合装置。

30. 請求項17 から 請求項25 までおよび 請求項11 から 請求項12 までに記載の画像照合装置において、

前記反射率測定手段がなく、別途図面等から反射率を入力する

ことを特徴とする画像照合装置。

31. 請求項17 から 請求項27 まで に記載の画像照合装置において、前記登録手段に、

位置姿勢の推定を行う為に必要な情報として、照合対象物体の特徴的な見え方 をする部位である特徴点の位置情報を、登録過程において登録データに付与す る特徴点抽出手段を追加し、

前記位置姿勢推定手段において前記付与した特徴点の位置情報を利用する

ことを特徴とする画像照合装置。

32. 請求項17 から 請求項30 までに記載 の画像照合装置において、自動車を前記照合対象とすることを特徴とする自動 車画像照合装置。
33. 請求項17 から 請求項30 までに記載 の画像照合装置において、人間の顔を前記照合対象とすることを特徴とする顔 画像照合装置。

34. 請求項17 から 請求項32 までに 記載の画像照合装置において、入力画像を撮影する撮像手段として、フィルム や写真、印刷物等を読み取る画像入力装置を用いることを特徴とする画像照合 装置。

記憶媒体に関する請求項は記述していません。申し訳ございませんが補填して いただければ幸いです。

発明の詳細な説明

発明の適用分野

画像による物体の照合技術に関し、特に認識対象となる物体の3次元形状と、 表面反射率や色情報などをあらかじめ登録しておくことにより、画像上での物 体の位置や姿勢、照明条件などの撮影条件の変動に対して頑強なことを特徴と する画像照合方法、照合装置、及び該画像照合をデータ処理装置で実行させる 記録媒体に関する。

従来の技術

画像照合技術とは［図5］に示したように、3次元空間上に適当に 配置された物体が何であるのかを、カメラなどの画像撮像デバイスにより取得 した入力画像（群）を利用して照合する技術である。画像照合のプロセスは照合対象を記録しておく登録過程と、入力された画像(群)に何が撮影されている かを登録データと比較照合してゆく照合過程の二つから構成されている。それ ぞれの過程において撮像された画像は、2 次元的な広がりを持つ2次元画像の まま用いたり、また文献(1)（「三次元画像計測」、井口・佐藤、昭光堂)に記 載されている技術などにより、3次元形状などに変換して利用する。 従来の画 像照合技術を、以下で文献を参照しながら説明する。

2次元画像を登録しておき入力として2次元画像を用いる画像照合技術の一例と して、文献 (2)(特許第2872776号「顔画像照合装置」) で示される技術がある。 本技術は照合対象として人間の顔を想定しており、［図13］ のような 構成をとっている。登録時はカメラ11により撮影された2次元画像を、記憶手 段12に記憶しておく。照合時は、カメラ13で2次元の顔画像を入力画像として 撮影し、正規化手段14によって、前記入力画像から目や鼻の位置など姿勢や大 きさの基準となる顔特徴点を画像処理技術により抽出し、該特徴点の座標位置 を基準として画像上において2 次元的な位置と大きさの正規化を行った正規化 画像を出力する。最後に画像比較手段15 によって記憶手段12から読み出され る登録画像と前記正規化画像をパターン認識技術により比較し、照合結果を出 力する。

また、3次元形状を用いた従来の照合技術の例として、文献(3)(特開平 9-259271「人物照合装置」)で示される技術がある。本技術では、［図14］ のような構成をとる。登録時には、3次元形状カラー情報計測 手段21により照合対象物体の3次元形状とカラー情報を測定し、記憶手段22に 記憶しておく。照合時にも、3次元形状カラー情報計測手段23により入力デー タとして3次元形状とカラー情報を測定し、平行移動・回転手段24により、前 記入力データを重心が登録データと一致する様に平行移動し、微少回転を加え たデータを多数生成し、最小誤差計算手段25によって誤差の最小値を求めるこ とで3次元的な位置姿勢の補正を行い、該最小誤差に基づいて照合を行う。

文献(5)(特開平6-168317「個人識別装置」)は、［図15］ のような構成 をとり、登録時と照合時ともに2 次元画像を撮影する照合技術である。登録時 にはカメラ41により2次元画像を撮影し、特徴抽出手段42において輝度変動の 大きな画素位置を検出して特徴点位置を出力し、記憶手段43に記憶する。照合 時には、カメラ44により入力画像として2次元画像を撮影し、特徴抽出手段45 において輝度変動の大きな画素位置を検出して特徴点位置を出力し、照合手段 47において前記登録されている特徴点位置と前記入力画像の特徴点位置を比較 することで照合を行っている。このとき認識対象物体の位置や姿勢の変動を吸 収するために、位置姿勢正規化手段46において標準的な物体3次元形状モデル をあらかじめ用意しておき、該標準3次元形状モデルを利用して位置姿勢を正 規化する。

位置や姿勢の変動だけでなく、照明条件による変動をも補正するためには、登 録過程・照合過程双方で通常の2次元画像だけを用いる技術として、文献(6)（「Visual Learning and Recognition of 3-D Objects from Appearance」, Hiroshi Murase and Shree K. Nayer, Int. J. Computer Vision, vol.14, pp.5-24, 1995)がある。
この技術では［図16］ のような構成を取り、 撮影手段71により、登録する各物体について入力画像において考えられるあら ゆる姿勢や照明条件を網羅したサンプル画像群を撮影し、多様体計算手段72に より前記画像群の変化を十分表せるような基底画像群を主成分分析により求め、 該基底画像群との相関を特徴とする特徴空間を生成し、前記サンプル画像群の 特徴空間における軌跡を多様体として求め、記憶手段73に記憶しておく。照合 時に

はカメラ74により入力画像として2次元画像を撮影し、距離計算手段75 に おいて前記入力画像と前記多様体との特徴空間における距離を計算し、該距離 を尺度として照合を行う。これにより様々な位置姿勢や照明条件で撮影された 入力画像の照合を可能にしている。

物体の位置姿勢が固定である場合の照明条件による2次元画像の変化について は文献(7)(「What Is the Set of Images of an Object Under All Possible Illumination Conditions?」, Peter N. Belhumeur and David J. Kriegman, Int. J. Computer Vision, vol.28, pp.245-260,1998) において詳しく分析さ れている。物体の位置姿勢を固定すれば、任意の照明条件での画像は、一つの 点光源のもとでの画像の和に分解してあらわすことができる。したがって、任 意の数の光源のもとでの画像は、それぞれひとつずつの光源の強さを係数とし て、そのひとつの光源のもとでの画像の線形和であらわすことができる。

前記の分析に基づき、前記文献(7)ではIllumination Subspace Method(以下方 法(8) で参照する) と呼ばれる[図17] のような構成を取る方法を提 案している。撮影手段51において、できるだけ影になる画素がないような異な る照明条件を3 つ以上設定し、画像群を撮影する。法線計算手段52において、 該画像群から主成分分析により、画像の各画素に対応する物体表面の反射率と 法線ベクトルの積に相当するベクトル群を求める。続いて、画像生成手段53に おいて、該ベクトル群の任意の2個のベクトルの外積であらわされる方向に照 明がある場合の画像であるextreme rayと呼ばれる画像群を生成し、記憶手段 54に記憶する。照合時にはカメラ55によって2次元画像である入力画像を撮影 する。物体表面の反射特性が完全散乱であり、かつ、形状が凸である場合には、 任意の照明条件の下での画像は前記extreme ray群の係数が正である線形和と してあらわせるので、該係数群を、負にならないという条件の下での最小二乗 法を用いて計算することができる。照明補正手段56において、前記最小二乗計 算を行い、求まった係数群を用いたextreme ray 群の線形和により入力画像と 同じ照明条件での物体の画像である比較画像を生成する。画像比較手段57 に おいて、該比較画像と前記入力画像の類似度を計算することで照合処理を行う。

文献(10) (「illumination Cones for Recognition Under Variable Lighting:Faces」, A.S. Georghiades, Proc. IEEE Int. Conf. CVPR, pp.52--58,1998) では方法(8)においてextreme rayを計算す る際に、光線追跡などのコンピュータグラフィックスの技術を用いて、物体の 3次元形状からどの画素が影になるかを計算し、影をつける処理を行う方法を 示している。これにより形状が凸でない形状の物体にも方法(8)が適用できる としている。

また、前記文献(7)ではSampling Method(以下方法(9)として参照)として [図18] のような構成を取る方法も提案している。前記の方法(8)のよ うに全てのextreme rayを計算することは手間がかかるので、登録時に、撮影 手段61において、例えば [図4] の θ, ϕ の角度がなるべ く等間隔に全体を覆うように適当な数の照明方向を設定して画像群を撮影し、 該画像群をextreme ray として代用する。以降は方法(8)と同様に非負最小二 乗法を適用して照明補正を行い、物体認識を行う。

発明が解決しようとする課題

照合対象となる物体は特に固定や調節などをしない限り、カメラなどの画像撮 像デバイスの前で3次元的な平行移動、回転移動などを伴うのが普通である。 また、屋外などでは刻々と照明条件も変動してゆくことから明らかなように、 照合処理対象として入力される2次元画像上では、見かけ上非常に大きな変動 を伴っている。従来技術はこれらによる変動を十分補正することができていな いため、応用範囲が非常に限られてしまうという問題点がある。以下具体的に 各文献における方法について問題点を詳しく述べる。

文献(2)に記載されているような単なる2次元画像同士での照合技術では、照合 対象となる物体の3次元的な回転変動や画像撮影時の照明条件変動による2 次 元画像上での見かけ上の変動に対応することができず、応用範囲が極めて限定 されている。

文献(3) の照合技術では、登録時だけでなく照合時にも3次元形状を必 要とするために、照合装置には文献(1)に示されているような3次元形状計測装 置が必須となり、高価となってしまう問題があった。これは、登録時と異なる 場所や、複数の場所で入力画像を撮影し照合を行いたい場合などに特に問題で ある。また形状の計測をするためには計測が終了するまで照合対象が静止して いなければならなかったり、暗室や薄暗い環境でなければ精度の良い形状デー タが得られないという問題があり、やはり応用範囲が限られてしまう。

文献(5)に示されているような、輝度変動の大きな画素位置を検出する方法は、 3次元的な曲率が非常に大きな積み木や、また反射率の変動が非常に大きい白 板上の黒いマーカなどには有効であるが、該文献(5)中で言及されているよう な人間の顔には向かないことが知られていることからも、安定な座標位置検出 は一般に困難である。また該文献(5)では照合対象となる物体群の標準的な3 次元形状により姿勢を補正するとあるが、該物体群の各物体間において形状の 類似度が高くない場合には適用ができないという問題点があった。

文献(6)の技術では、入力画像の照明条件として複数の光源や拡張光源など様々 な照明条件を考慮すると、これらを網羅するサンプル画像は膨大な量が必要に なってしまう。また、特徴空間における多様体の形状について何も仮定されて いないため、入力画像との距離を求める際に撮影条件のパラメタに対する探索 を要する。したがって多くの計算量が必要となるという問題があった。

方法(8),方法(9)記載の方法では対象物体に多数の方向から照明を当て た画像を撮影する必要があり、登録時に特別な照明装置が必要となることや、 機材の配置の問題から十分正確な照明条件の設定が困難になるなどの問題があ る。また、方法(8),(9)記載の方法はともに、物体の位置や姿勢が変わった場 合には、その位置姿勢における多数の照明条件の下での画像を撮影し、はじめ からすべて計算しなおす必要がある。したがって、入力画像において想定され るあらゆる位置姿勢における多数の照明条件の下での画像を撮影しなければな らないため登録処理に手間がかかることや、あらかじめ登録されていない位置 姿勢で撮影された画像は照合することができないなどの問題がある。

さらに、方法(8)の技術では、形状の複雑さに応じてextreme rayを計算する手 続きに非常に多くの計算量を要す

る。文献(7)によれば、物体表面の法線ベクトルのうち線形独立なものが m 個ある場合、extreme rayの数は最大で $m(m-1)$ 個である。したがって、物体形状が積み木のように単純なものでない限り、膨大な数の画像を計算しなければならなくなるため、複雑な形状の一般的な物体に対して全てのextreme rayを計算することは計算量の点で問題がある。また、物体形状が凸でなく、他の部分が光源を遮蔽して生じる影がある場合にはそのまま適用することはできない。

また、係数が負とならない条件の下での最小二乗法の計算もextreme rayの数に関係して非常に多くの計算量を要するという問題がある。方法(9)の技術では、この問題に加えて、どの程度の数の基底画像を用いれば十分な性能が得られるかが不明確であることも問題である。

また、方法(8),(9)ともに物体表面の反射特性が完全散乱面であることを仮定しているため、鏡面反射が存在したり、拡散反射も完全散乱でないような物体に対してはそのままでは適用できない。一般に、多くの物体はその表面の反射特性が完全散乱ではない。

発明の目的

本発明の目的は、

第1に、照合に用いる入力データとして3次元形状を必要とせず通常のカメラで撮影した2次元画像を照合でき、

第2に、入力画像における物体の3次元的な位置姿勢の変化を補正可能であり、

第3に、登録時に必要なデータが簡便に測定可能であり、

第4に、様々な照明条件において撮影された入力画像に対し照明条件の補正を高速な処理によって実現できること

を特徴とする画像照合方法、装置および記憶媒体を提供することにある。

課題を解決するための手段

請求項1 記載の発明は、照合を行うための各個人のデータをデータベースに登録する登録過程において、物体の3次元形状と、物体の表面の反射率を測定し、該3次元形状と反射率を記憶しておく。入力される画像に対して登録データとの照合を行う照合過程においては、まず、ビデオカメラ等の撮像装置を用いて入力画像として2次元画像を撮影する。そして、あらかじめ与えておいた一定の位置姿勢にあって、様々な照明条件のもとでの物体の画像である照明変動画像群を登録されている3次元形状と反射率データを用いて生成し、該照明変動画像群から入力画像に最も近い画像を求めて比較画像として生成し、該比較画像と前記入力画像の類似度の評価値を計算し、該類似度の評価値に基づいて、対象物体であるかどうかの確認、登録されているどの物体であるかの検索、登録されている物体のうち似ている物体の検索、等の処理を行うことを特徴とする。

請求項2 記載の発明は、請求項1 記載の発明において、前記比較画像の生成が、前記照明変動画像群ではられる画像空間である照明変動空間を生成し、該照明変動空間内にあって入力画像に最も近い画像を比較画像として生成するものであることを特徴とする。

請求項3 記載の発明は、請求項2 記載の発明において、前記照明変動空間の生成が、前記照明変動画像群を主成分分析などの統計的解析を施すことにより、照明条件により画像上に現れている変動要因の大部分を覆うような空間の基底ベクトルを求めることで、照明変動空間を生成するものであり、前記比較画像の生成が、前記基底ベクトルと入力画像との間の相関を求め、該相関を元に基底ベクトルから入力画像に最も近い比較画像を生成し出力するものであることを特徴とする。

請求項4 記載の発明は、請求項1 記載の発明において、前記照明変動画像群の生成を、前記登録過程においてあらかじめ行っておき、該照明変動画像群を記憶しておき、前記照合過程における比較画像の生成において、該登録されている照明変動画像群を利用するものであることを特徴とする。

請求項5 記載の発明は、請求項2 記載の発明において、前記照合過程における照明変動画像群の生成および照明変動空間の生成をあらかじめ登録過程において行い該生成された照明変動空間を記憶しておき、前記照合過程の比較画像生成において、該登録されている照明変動空間を利用することを特徴とする。

請求項6 記載の発明は、請求項3 記載の発明において、前記照合過程における照明変動画像群の生成および基底ベクトル群の生成をあらかじめ登録過程において行い該生成された基底ベクトル群を記憶しておき、前記照合過程の比較画像生成において、該登録されている基底ベクトル群を利用することを特徴とする。

請求項7 記載の発明は、請求項1 から 請求項3 記載の発明において、前記あらかじめ与えられた一定の位置姿勢を用いるのではなく、前記入力画像に写っている物体の位置姿勢のパラメタを別途入力することを特徴とする。

請求項8 記載の発明は、請求項1 から 請求項3 記載の発明において、前記あらかじめ与えられた一定の位置姿勢を用いるのではなく、前記入力画像に写っている物体の位置姿勢を前記登録されている3次元形状と反射率を利用して推定することを特徴とする。

請求項9 に記載の発明は、請求項1 から 請求項8 記載の画像照合方法において、前記登録過程において反射率を測定する代わりに、適当な照明の下で画像情報を撮影し、以降の処理において反射率の代用として前記画像

情報を利用することを特徴としている。

すなわち 請求項9 記載の発明では、物体の表面の反射率のかわりに、 適当な照明条件を設定して撮影した画像を代用できることを利用する。例えば 物体の全体に一様に光が当たるような影のできにくい照明条件の下で撮影した 画像は、その輝度値が反射率にほぼ比例しているとみなせることを利用する。

前記の反射率測定手段に代用する画像の撮影手段に用いることのできる方法の 一例として次のような方法がある。登録する物体前方に半球型のやぐらを設置 し、適当な数のランプを取り付ける。そして、全てのランプを同時に点灯させ て画像を撮影する。この他にも光を拡散させ一様な光を物体に当てるために、 反射板を用いるなど種々の方法が利用可能である。

請求項10 記載の発明では、 請求項1 から 請求項8 に記載の発明における登録過程の反射率の測定を、照明条件変化処理において 設定する照明条件と同等になるように適当な数の照明条件を設定し、その条件 で画像を撮影するテクスチャ画像群の撮影に置き換えること、また、 請求項1 から 請求項8 に記載の発明における照明変動画像群 の生成において照明条件を変動させる代わりに前記テクスチャ画像群の各画像 を用いることで照明変動画像を生成すること、および、前記変更点以外の処理 は 請求項1 から 請求項8 記載の発明と同等であること、を特 徴としている。

すなわち 請求項10 記載の発明では、照合対象物体の画像の照明条件 による変動を包含する照明変動空間を生成するのに十分なサンプル画像が生成 できるだけの適当な数の照明条件を設定し、その照明条件の下で画像情報を撮 影しておけば、反射率を測定したりコンピュータグラフィックスによる画像生 成における照明条件の設定や光線追跡による影の生成などの処理を行わなくて も、照明変動空間を生成するためのサンプル画像が生成できることを利用する。

前記テクスチャ画像撮影処理に用いることのできる方法の一例として次のよう な方法がある。登録する物体前方に半球型のやぐらを設置し、一様な間隔で適 当な数のランプを取り付ける。そして、各ランプを点灯させながら画像を撮影 する。この他にもランプをマニピュレータに取り付けて移動させながら画像を 撮影するなど様々な方法が利用可能である。

撮影した複数のテクスチャ画像は3次元形状とあわせて登録データとして記憶 しておく。照合過程においては、照明条件変化処理を行わず、記憶してあるテ クスチャ画像群を順次読み出し、位置姿勢推定処理において推定された位置姿 勢にあって、物体表面の輝度値が各テクスチャ画像に等しいような画像をコン ピュータグラフィックスにより生成し、サンプル画像として出力する。以下の 処理は 請求項1 から 請求項8 に記載の発明と同等とする。

請求項11 記載の発明では、 請求項1 から 請求項10 に記載の画像照合方法において、登録過程において複数 の照合対象となる物体の3 次元形状を測定する代わりに、1つないし少数の3次 元形状を測定するだけで、該1つの3次元形状ないし少数の3次元形状の平均と なる3次元形状1つを出力し、照合対象となる全ての物体の形状は計測せず、反 射率の測定が、照合対象となる全ての物体について反射率の計測もしくは一つ ないし複数の照明条件の下での画像情報撮影を行うものであり、以降の処理に おいては3次元形状として前記の平均の形状データだけを用いることを特徴と する。

すなわち 請求項11 記載の発明では、特に互いに形状が類似している 物体の場合には、全ての物体の3次元形状を測定しなくても、代表的な形状デー タをかわりに用いることで、位置姿勢推定処理および照明補正処理が行えるこ とを利用している。

平均3次元形状の生成に利用できる方法の一例として、次のような方法が利用 できる。ここでは2つの物体の平均形状を求める例をもって説明する。まず、 物体1と物体2の3 次元形状を測定する。そして、 ［図9］ の左図に 示すように、2つの物体の3次元形状データを重心を一致させるように平行移動 し、左図の z 軸に垂直な断面を考え、断面を適当な間隔で z 軸方向に動かし ながら、各断面上で平均形状を計算する。 ［図9］ 右図に示すよ うに、断面上で重心から物体の外側に向かった直線である平均計算軸を考え、 物体1、物体2 の形状との交点を P_1, P_2 とする。平均形状である点 P_m の の3次元座標は、二つの物体表面上の点 P_1, P_2 の3次元座標 (x_1, y_1, z_1) (x_2, y_2, z_2) を平均した $\left(\frac{x_1+x_2}{2}, \frac{y_1+y_2}{2}, \frac{z_1+z_2}{2}\right)$ とする。この 処理を平均計算軸を重心の周りに適当な間隔で回転しながら繰り返し行ってい くことにより、物体1と物体2の平均形状データが生成できる。3次元形状測定 処理では、該平均形状データを出力する。

この方法は物体の数が3個以上になっても適用できる。また、平均形状を求め る方法はこの他にも様々なものが利用可能である。

以下の照合過程の処理においては、データ記憶処理から前記平均形状を読み出 し、各物体の3次元形状データに代用する。

請求項12 記載の発明では、 請求項1 から 請求項11 までに記載の画像照合方法において、3 次元形状測定処 理がなく、別途図面等から3次元形状を入力しておくことを特徴する。

すなわち 請求項12 の発明では、一例として、照合対象となる物体 が工業製品など設計図の存在する物体である場合や、建築物など三次元形状の 測定が一般の3次元形状計測装置では困難であり別途測量等を行い形状を測定する場合に、図面等から物体の3次元形状を入力できることを利用している。

請求項13 記載の発明では、 請求項1 から 請求項11 ま でに記載の画像照合方法において、反射率測定処理がなく、別途図面等から反射率 を入力しておくことを特徴する。

すなわち 請求項13 記載の発明では、一例として、照合対象とな る物体が工業製品など物体表面の各部位の塗装の反射率が既知の物体である場 合に、図面等から物体の3次元形状を入力できることを利用している。

請求項14 記載の発明は、 請求項1 から 請求項13 まで に記載の画像照合方法において、位置姿勢推定処理を行う為に必要な情報とし て、照合対象物体の特徴的な部位の位置情報を、登録過程において登録データ に付与して登録すること特徴とする。

すなわち 請求項14 記載の発明では、入力画像において照合対象物体の特徴 点の位置を抽出し、該特徴点の3次元座標を登録データから知ることができれ ば、前記特徴点の画像上の位置と3次元座標を用いて入力画像中の物体の位置 姿勢および撮像装置のパラメタを自動的に求めることができることを利用して いる。

複数の点について画像上の位置と3次元座標が既知である場合に入力画像中の 物体の位置姿勢および撮像装置のパラメタを自動的に求める方法としてはカメ ラキャリブレーションの方法が利用できる。これには多くの方法があり、一例 として文献(15)(「An Efficient and Accurate Camera Calibration Technique for 3D Machine Vision」,Roger Y. Tsai,Proc. CVPR'86, pp.364--374,1986)に記載の方法があるが、ここでは詳細については省略する。

発明の実施の形態

本発明では、物体の３次元形状と表面の反射率を登録しておくことにより、任 意の位置姿勢、任意の照明条件の下での物体の画像を生成できること、および、 該位置姿勢にある照合対象物体の様々な照明条件の下での画像群が、画像空間 内の低次元の部分空間として表現できることを利用する。

まず、位置姿勢推定処理について説明する。位置姿勢推定処理では、入力画像 を撮影したときの撮影条件である物体と撮像装置との間の位置・姿勢、撮像装 置の内部パラメタ等を推定する。この位置姿勢推定処理は手動または自動で行 う様々な方法を利用することができる。

例えば手動で行う方法の一例として、照合対象物体の3次元形状と反射率を用 いてコンピュータグラフィックスにより生成した画像（以下CG画像と呼ぶ）と 入力画像を重ねあわせたときに両者ができるだけぴったり重なるように、対話 型のインタフェースを用いて位置姿勢のパラメタを調節したり入力する方法を 利用できる。

自動で位置姿勢の推定を行う方法の一例としては、様々な位置姿勢での照合対 象物体のCG画像を生成し、各CG画像を入力画像と比較し、最も似ている画像を 求めることで位置姿勢や撮像装置のパラメタを決定する方法が利用できる。

また、画像を比較する代りに物体の画像上で輝度値が大きく変化する部分など、 特徴的な領域や点（以下では特徴点と呼ぶ）の位置を入力画像とCG画像から検 出し、前記特徴点の位置がもっとも近くなるようなCG画像を求めることで物体 の位置姿勢や撮像装置のパラメタを計算する方法も利用できる。

また、特徴点位置を入力画像から検出し、各特徴点間の位置関係についての情 報を利用して物体の位置姿勢を求める方法もある。文献(13)(「An analytic solution for the pose determination of human faces from a monocular image」, Shinn-Ying Ho , Hui-Ling Huang, Pattern Recognition Letters,Vol.19,1045-1054,1998)には、照合対象物体として人間の顔を用いる 場合に目尻や口元といった特徴点を用い、両目の特徴点を結ぶ直線と左右の口 元の特徴点を結ぶ直線が互いに平行であるなどの位置関係を利用して位置姿勢 を求める方法が記述されている。

また、 請求項14 に記載の発明のように物体の特徴点の位置を登録しておく ことで、カメラキャリブレーションの方法が利用できる。これには多くの方法 があり、一例として文献(15)(「An Efficient and Accurate Camera Calibration Technique for 3D Machine Vision」,Roger Y. Tsai,Proc. CVPR'86, pp.364--374,1986)に記載の方法がある。

次に、照明補正処理について説明する。

物体表面の反射率特性として完全散乱面を仮定し、物体形状が凸であり他の部 分による光源の遮蔽によって生じる影がなく、光源が無限遠にあるとすれば、 画像の各画素 (u,v)の輝度値 $I(u,v)$は、画素に対応している物体表面の反 射率 $B(u,v)$、法線方向 $\vec{N}(u,v)$、各照明の強度 l_i、方向 $\vec{L}_i$により次の［式1］ でモデル化できる。

［式1］

$$I(u,v) \quad = \quad B(u,v)\max(\sum_i(l_i\vec{L}_i\cdot\vec{N}(u,v)),0)$$

ここで、 $\max()$の効果を無視すれば、照明が複数ある場合などを含め、任意 の照明条件は次の［式2］ のように一つの照明ベクトル $\vec{L}$で あらわすことができる。

［式2］

$$I(u,v) = B(u,v)\vec{N}(u,v)\cdot\vec{L} \qquad (\vec{L} = \sum_i l_i\vec{L}_i)$$

したがって、照明変動により生成される物体の画像の自由度は $\vec{L}$ の次元、 すなわち高々3次元になるが、実際には、 $\max()$ の効果や、物体の他の部分 により光源が遮蔽されて影ができること、および反射特性が完全散乱面でない ことなどによる効果があるのでこれよりも高次元となる。しかし大部分が3次 元の部分空間であらわせることから、実際の画像変動も低次元の部分空間とし て十分近似できる。以下、この低次元の部分空間を各物体の照明変動空間と呼 ぶ。

照明変動空間の基底ベクトルを得るために、主成分分析を用いる。照明変動に より生成される対象物体の画像(以下では照明変動画像と呼ぶ)を多数用意し、 照明条件の変動によってできる画像全体の集合を近似する。照明変動画像群の 各画像は、単一の無限遠にある点光源のもとでの画像とし、光源の方向を入力 画像の撮影時の照明条件として考えられる全ての方向を包含するように適当な 間隔で設定した多数の画像を用意する。複数の照明の下での画像は単一の照明 の画像の和でかけるので、単一照明下の画像のみで十分である。照明変動画像 群の生成には登録されている３次元形状データおよび表面の反射率データを用 いるが、その生成手段の一例としてコンピュータグラフィックスの基本機能を 利用する方法がある。コンピュータグラフィックスの機能については文献(14)（「OpenGLプログラミングガイド」,Mason Woo,Jackie Neider,Tom Davis,アジ ソン・ウェスレイ・パブリシャーズ・ジャパン)に詳しく述べられている。 コンピュータに標準的に備わっている機能としては、物体の表面の反射特性を 完全散乱モデルとし、陰影だけを生成するものが多いが、本発明においては、 実際の物体表面の反射特性にできるだけ近い反射モデルを使用し、鏡面反射な ども考慮することや、陰影だけでなく光線追跡の技術を用いて影を再現するな ど、できるだけ現実に近い画像を生成できるようにする。

以上述べたように画像生成にコンピュータグラフィックスの機能を利用するの は一例であり、数値計算により照合に必要な画素について輝度値を計算するこ とで画像を生成することも、もちろん可能である。

以下、画像全体のうち照合に用いる領域にある画素の輝度値を縦に並べたベク トルで画像をあらわす。照明変動画像群の画像が N 個のとき、各画像をベク トル $\vec{K}_i(i=1,2,\cdots,N)$ であらわすと、 V は次の［式3］であらわされる。

［式3］

$$S=\begin{bmatrix}\vec{K}_1 & \vec{K}_2 & \cdots & \vec{K}_N\end{bmatrix}$$

$$V=\frac{1}{N}SS^T$$

次に、 V の各固有値 σ_i と固有ベクトル $\vec{B}_i$ を固有値の大きい順 に M 個まで求める。そして、物体 j の照明変動空間をベクトル $\{\vec{B}_i\}$ を基底とする M 次元線形空間 Ψ_j で近似する。ここで照明 変動空間の次元 M は、照明補正処理に必要とされている精度との兼ね合いで 決めることができる。 M 個の固有ベクトルを使った場合、その固有値の累積 寄与率が次の［式4］で計算できる。

［式4］

$$\frac{\sum_{i=1}^{M}\sigma_i}{\sum_{i=1}^{N}\sigma_i}\times 100\ [\%]$$

累積寄与率は、輝度値の差を用いて画像の誤差を評価したときに、照明変動空 間がどの程度正確に照明変動画像群を表現できるかを表す数値である。この値 に対して閾値を定めておけば、その閾値を上回るのに必要な次元数として M を自動的に決定することができる。

物体の照合は、入力画像 $\vec{I}_q$ と照合対象物体の照明変動空間の距離を尺 度として行うことができる。この距離は照明変動空間 Ψ_j 内にあって最も 入力画像に近い画像 $\vec{I}_c$ と入力画像と間の距離として計算できる。距離の尺度としては様々なものが利用可能であるが、ここでは輝度値の2乗誤差を 直接用いる例をもって説明する。

この距離尺度を用いる場合には、 Ψ_j 内でもっとも $\vec{I}_q$ に近い画像 $\vec{I}_c$ は次の［式5］で生成できる。

［式5］

$$\vec{I}_c=\sum_{i=1}^{n}(\vec{I}_q\cdot\vec{B}_i)\vec{B}_i$$

比較画像 $\vec{I}_c$ と入力画像 $\vec{I}_q$ との距離 D (輝度値の差の2乗和)は次 の［式6］で計算できる。

[式6] $$D = |\vec{I}_q - \vec{I}_c|^2$$

この値 D を入力画像と登録データの類似度の評価値とし、これに基づいて、 対象物体であるかどうかの確認、登録されているどの物体であるかの検索、登 録されている物体のうち似ている物体の検索、等の処理を行う判定処理を行う。 例えば簡単な閾値処理で対象物体であるかの確認を行う場合は、ある閾値 D' を定めておき、$D < D'$ であれば対象物体であると決定する。

発明の実施例

［図1］ は本発明の画像照合装置の第1の実施例の処理の流れを示す ブロック図、 ［図2］ は構成図である。本実施例は 請求項25 に記載の発明に相当する。

［図1］ に示されるように、登録手段では3次元形状測定装置を用い て物体の3次元形状と、物体表面の反射率または色情報を測定し、両者を記憶 しておく。照合手段では、ビデオカメラ等の撮像装置を用いて2次元の画像を 撮影し、照合処理を行う処理装置に取り込み、照合処理を行う。

まず、登録手段100において、物体の照合に用いる登録データとして、物体の3 次元形状と、表面の反射率を登録しておく。

3次元形状測定手段110では、3次元形状測定装置を用いて物体の3次元形状を測 定する。例えば(特願平11-123687)の3 次元形状測定装置を利用できる。この 他にも様々な装置が利用可能である。

反射率測定手段120では、3次元形状に対応する物体の表面の反射率を測定する。 例えば前記(特願平11-123687)の3次元形状測定装置を用いれば、3次元形状と 同時に表面の色情報を測定することができる。以下ではこの色情報を反射率に 代用する。

データ記憶手段130では、登録された各物体の物体の3次元形状および反射率デー タを記憶保持し、照合手段200の処理の為に適時読み出す。

以上の登録手段100の処理を行った物体に対して、以下の照合手段200において 画像を用いた物体照合処理を行う。

照合手段200において、カメラなどの撮像装置を利用して照合対象となる入力 画像を撮影し、照合手段である処理装置に取り込む。

撮影手段210では、カメラやビデオカメラ等の撮像装置を用いて照合対象とな る入力画像が撮影される。

位置姿勢推定手段220では、入力画像を撮影したときの撮影条件である物体の 位置姿勢や撮像装置のパラメタ等を推定する。例えば位置姿勢パラメタとして 物体の平行移動距離 (T_x, T_y, T_z)、回転角度 (R_x, R_y, R_z)、カメラの焦 点距離 f、視野角 α を用いる。そして、これらのパラメタを利用者が画面を見ながら手動で調整できるような対話型のインタフェースを処理装置上 に備えておく。例えば画面には前記8つの位置姿勢パラメタを用いてコンピュー タグラフィックスにより生成された照合対象物体の画像と、入力画像がスーパー インポーズ法により重ね合わされて表示されている。利用者は2つの画像がぴっ たり重なるように前記8 つのパラメタの値を調節し、適切なパラメタを決定す る。この対話型のインタフェースについては一例であり、様々な形態のものが 利用可能である。また、このような対話型インタフェースを用いなくとも、自 動的に位置姿勢パラメタの計算を行ってもよい。

照明補正手段230では、前記位置姿勢推定手段220の結果を利用して、入力画像 と同じ位置姿勢にあって最も近い照明条件の画像を、比較画像として生成する。 ［図3］ は照明補正手段230の機能の詳細な構成を示すブロック図で ある。

まず、照明条件変化手段231により、物体の照明変動空間を近似するのに十分 な数の照明条件を設定する。例えば、無限遠にある一つの点光源を考え、 ［図4］ に示すような物体を中心とした球面の経度、緯度をあら わす (θ, ϕ) の角度で光源の方向を示すとし、 θ と ϕ を1 0° おきに-90° から9 0° まで変化させ、361種類の照明条件群を設定する。こ の光源の種類、照明方向の設定間隔や範囲の決め方は一例であり、種々変更可 能である。

画像生成手段232では、データ記憶手段130から照合対象である物体 j の3次元 形状と反射率を読み込み、位置姿勢推定手段220から入力される位置姿勢パラ メタと、照明条件変化手段231から入力される照明条件群における照明変動画 像群を、コンピュータグラフィックスの機能を使って生成する。この処理は、 一例として、グラフィックス機能を備えたコンピュータの基本機能をもって実 現できる。コンピュータグラフィックスを用いた画像生成においては様々な物 体表面の反射モデル、カメラモデル等を使うことができる。一例としては、カ メラモデルとしてピンホールカメラモデル、物体表面の反射モデルとして完全 散乱モデルを用いることができる。これらのモデルは一例であり、光線追跡処 理を行って影をつけたり、てかりをつけるために他の様々な反射モデルを用い ることもできる。この画像生成処理において、物体表面の反射特性や光源、カ メラのモデルをより現実に近い正確なものとすることで、照合性能を向上させ ることができる。また、この画像生成はコンピュータグラフィックスを用いな くとも、数値計算によって実現可能である。

照明変動空間生成手段233では、画像生成手段232で生成された照明変動画像群 から照明変動空間を［式3］にしたがって計算し、計算された基底 ベクトル群を物体の照明変動画像空間 Ψ_j として出力する。本実施例では固有値の大きい順に M 個の基底ベクトルを求め、 Ψ_j として出力する。 この基底ベクトルの数 M を一例として［式4］で計算される累積 寄与率が95%を超える数として決定するには、照明変動画像群の画像の数に等 しい 361 または画素数がそれ以下である場合は画素数の数を N とし、 N 個 の固有値を求め、 $\frac{\sum_{i=1}^{M}\sigma_i}{\sum_{i=1}^{361}\sigma_i} \geq 0.95$ となる数 M を求めて決定する。 M の決定法は他にも様々な基準を適用して決めることが可能である。

照明条件推定手段234では、［式5］によって、入力画像を用いて 照明変動画像空間 Ψ_j 内にあって入力画像に最も近い画像を比較画像とし て生成する。

画像比較手段240では、入力画像と生成された比較画像の類似度の評価値を計 算する。評価値の計算方法には様々な技術が利用できるが、その一例としては、［式6］のように画像の各画素の輝度値の差の二乗和などを用いることができる。この他に、文献(12)(「コンピュータによる顔の認識--サー ベイ--」,電子情報通信学会論文誌 D-II,Vol.J80-D-II,No.8,pp.2031--2046,1997)に詳しく述べられているような、 様々な技術も利用可能である。

照合判定手段250では、計算された評価値を閾値処理して照合対象物体である かの照合を行う。また、複数の物体が登録されている場合には、前記230から 240 の処理を行って評価値を計算し、どの物体に最も似ているかの検索を行う こともできる。また、登録されている物体のうちある一定以上の評価値を持っ ている物体として、似ている物体の検索を行うこともできる。

次に、本発明の第2の実施例について［図6］と［図7］を 参照して詳細に説明する。本実施例は 請求項26 に記載の発明に相 当する。

［図6］は本発明の画像照合装置の第2の実施例の処理の流れを示す ブロック図である。本実施例は、第1の実施例と比較し、反射率測定手段120 において反射率を測定するかわりに、複数の照明条件下で画像を撮影しておき、それらの画像を反射率のかわりに用いて照明変動画像群を生成する点、および、 照明条件変化手段231がない点が異なる。

まず、登録手段2100において、物体の照合に用いる登録データとして、物体の 3 次元形状と、複数の照明条件のもとでの画像データを登録しておく。

3次元形状測定手段2110では、第1の実施例の3次元形状測定手段110と同様に（特願平11-123687)の3次元形状測定装置を用いて物体の3 次元形状を測定する。

テクスチャ画像撮影手段2120では、前記第1の実施例の照明条件変化手段から 出力される照明条件と同等な照明条件を実際に設定して物体の画像を撮影し、 テクスチャ画像として出力する。例えば物体前方に物体を中心とした半球型の やぐらを設置し、適当な間隔で適当な数のランプを取り付ける。一例としては、 物体に対して［図4］に示される角度 (θ, ϕ) において、 θ, ϕ について -90 度から 90 度までの範囲でそれぞれ 15 度間隔に ランプを取り付け、各ランプを点灯させながら1枚ずつ画像を撮影する。この 撮影方法および照明位置の設定方法は一例であり、この他にもランプをマニピュ レータに取り付けて移動させながら画像を撮影するなど様々な方法が利用可能 である。前記の方法により撮影した画像群をテクスチャ画像群として出力する。

データ記憶手段2130では、登録された各物体の物体の3 次元形状と、テクスチャ 画像群を記憶保持し、照合手段の処理の為に適時読み出す。

以上の登録手段2100の処理を行った物体に対して、以下の照合手段2200において 画像を用いた物体照合処理を行う。

撮影手段2210、位置姿勢推定手段2220は、それぞれ前記第1の実施例における 撮影手段210、位置姿勢推定手段220と同等の処理を行う。

本実施例の照明補正手段2200は、前記第1の実施例における照明条件変化手段 231がなく、画像生成手段2232において、前記テクスチャ画像撮影手段2120に おいて撮影したテクスチャ画像群をそのまま物体表面の輝度値として用いるこ とで照明変動画像群を生成する点が異なっている。［図7］は本実 施例における照明補正手段の流れを示すブロック図である。

画像生成手段2232では、データ記憶手段2130から照合対象である物体 j の3次 元形状とテクスチャ画像群を読み込み、位置姿勢推定手段2220から与えられた 位置姿勢と、前記テクスチャ画像群の各テクスチャ画像を用いて、照明変動画 像群をコンピュータグラフィックスの機能を使って生成する。この処理は、グ ラフィックス機能を備えたコンピュータの基本機能であるテクスチャマッピン グの技術を利用する。本実施例では様々なカメラモデルを利用することができ、 その一例としては、ピンホールカメラモデルを用いることができる。第1の実 施例と異なり、テクスチャ画像は現実に撮影された画像であるので、第1の実 施例のようにコンピュータグラフィックスの技術によって影やてかりを生成す る必要はない。

照明変動空間生成手段2233以下の処理は、第1の実施例と同等である。

次に、本発明の第3の実施例について詳細に説明する。本実施例は 請求項27 に記載の発明に相当する。

［図8］に本実施例のブロック図を示す。本実施例は、第1の実施例 と比較し、複数の物体を登録する場合に3次元形状測定手段3110 において全て の物体の3次元形状を測定するかわりに、1つないし少数の3次元形状を計測するだけで、平均形状生成手段3150において該1つないし少数の3次元形状の平均 となる3次元形状1 つを出力し、照合対象となる全ての物体の形状は計測しな い点、および、照合手段3200において前記平均の3次元形状を利用する点が異 なる。

まず、登録手段3100において、物体の照合に用いる登録データとして、物体1 と物体2の2つの物体について、3次元形状と、複数の照明条件のもとで の画像データを登録しておく。

3次元形状測定手段3110では、(特願平11-123687)の3次元形状測定装置を用いて 物体1と物体2の3 次元形状を測定する。

平均形状測定手段3150では、［図9］の左図に示すように、2つの 物体の3次元形状を重心を一致させるように平行移動し、左図の z軸に 垂直な断面を適当な間隔で設定し、それぞれの断面上で平均形状を計算する。［図9］右図に示すように、断面上で重心から物体の外側に向かっ て平均計算軸となる直線を考え、物体1、物体2の形状との交点を P_1, P_2と する。平均形状である点 P_mのの3次元座標は、二つの物体表面上の点 P_1, P_2の3次元座標 (x_1, y_1, z_1), (x_2, y_2, z_2)を平均した $\left(\frac{x_1+x_2}{2}, \frac{y_1+y_2}{2}, \frac{z_1+z_2}{2}\right)$とする。この 処理を平均計算軸を重心の周りに回転しながら適当な間隔で行うことにより、 物体1と物体2の平均形状が生成できる。平均形状測定手段3150では、該 平均形状を出力する。

反射率測定手段3120では、物体1,物体2それぞれの3次元形状に対応する 物体の表面の反射率を測定する。前記(特願平11-123687)の3次元形状測定装置 を用いれば、3次元形状と同時に表面の色情報を測定することができる。以下 ではこの色情報を反射率に代用する。平均形状の各点とここで測定した 各物体の色情報の対応は、次のようにして決定できる。すなわち、平均形状で ある点 P_mの3 次元座標を計算する際に用いた物体1、物体2の3次元形状デー タをそれぞれ P_1, P_2とすれば、平均形状 P_mに対応する物体1の反射率デー タは P_1に対応する反射率であり、平均形状 P_mに対応する物体2の 反射率は P_2に対応する反射率となる。

データ記憶手段3130では、3次元形状測定手段3110より出力される前記平均形 状と、反射率測定手段3120より出力される物体1,物体2のそれぞれの反射率を 記憶する。

照合手段3200における処理は、物体1,物体2の形状としてデータ記憶手段3130 から読み出される3次元形状が前記平均形状である点のみが第1の実施例と異な り、他の処理は全て同様である。

以上、本実施例では2個の物体を登録する際にその平均形状を記憶する実施例 を説明したが、これはあくまで1例であり、物体の数が3個以上になったり、そ のうち任意の数の物体の平均形状を求めて利用することも同様の処理により可 能である。

次に、本発明の第4の実施例について詳細に説明する。本実施例は 請求項30 に記載の発明に相当する。本実施例では照合対象物体の一例と して人の顔を用いる。

［図10］は本発明の画像照合装置の第4の実施例の処理の流れを示す ブロック図である。本実施例は、第1の実施例と比較し、登録手段4100 におい て、物体の画像上で輝度値が大きく変化するなどの特徴的な点の位置を抽出し 特徴点位置として出力する特徴点位置抽出手段4140が追加されている点、 データ記憶手段4130において物体の特徴点の位置も記憶する点、および、照合 手段4200の位置姿勢推定手段4220において、データ記憶手段4130から前記特 徴点位置を読み込み、物体の位置姿勢を自動的に推定する点が異なる。

まず、登録手段4100において、物体の照合に用いる登録データとして、物体の 3 次元形状、反射率を測定し、該3次元形状および反射率から物体の特徴点の3 次元座標を求め、前記3 次元形状と、反射率、特徴点位置を登録してお く。

3次元形状測定手段4110では、3次元形状測定装置を用いて物体の3次元形状を測 定する。本実施例では3次元形状測定装置の一例として(特願平11-123687)の3 次元形状測定装置を用いるが、この他にも様々な装置が利用可能である。

反射率測定手段4120では、3次元形状に対応する物体の表面の反射率を測 定する。前記(特願平11-123687)の3次元形状測定装置を用いれば、3次元形状 と同時に表面の色情報を測定することができる。以下ではこの色情報を反射率 に代用する。

特徴点抽出手段4140では、物体の画像上で輝度値が大きく変化する部分など、 特徴的な領域や点（以下では特徴点と呼ぶ）の位置を検出し、その3次元座標 を特徴点位置として出力する。一例として人物の顔を照合対象物体とす る場合には、目じりや口元など、反射率が大きく変化している部位や、鼻の頭 など3次元形状が大きく変化している部位を検出する。これは手動で行うこと もできるし、自動的に行う方法として前記文献（2）（特許第2872776号「顔画 像照合装置」）や、 文献(5)(特開平6-168317「個人識別装置」）記載の方法など様々な方法を利

用 できる。本実施例では［図12］に示すような位置の12個の点(0〜11)を特 徴点として用いる。これらの特徴点の定義は照合対象とする物体により様々に 変更可能であることはいうまでもない。以下ではこれら特徴点の3次元座標で ある特徴点位置を $\vec{A}_i = (x_i, y_i, z_i), (i = 0, 1, \cdots, 11)$ であらわす。

データ記憶手段4130では、登録された各物体の物体の3次元形状、反射率、 および特徴点位置を記憶保持し、照合手段の処理の為に適時読み出す。

以上の登録手段4100の処理を行った物体に対して、以下の照合手段4200において 画像を用いた物体照合処理を行う。

撮影手段4210では、カメラやビデオカメラ等の撮像装置を用いて照合対象とな る入力画像が撮影される。

位置姿勢推定手段4220では、入力画像を撮影したときの撮影条件である物体の 位置姿勢や撮像装置のパラメタ等を推定する。［図11］に位置姿勢推 定手段4220の詳細を説明するブロック図を示す。

特徴点抽出手段4221では、前記登録手段4100における特徴点抽出手段4140で抽 出した特徴点群 $\vec{A}_i$ と同じ特徴点の位置を入力画像から抽出し、画像上 での位置 $\vec{B}_i = (u_i, v_i), (i = 0, 1, 2, \cdots, 11)$ を入力画像特徴点位置と して出力する。これは人が処理装置の画面上に表示された入力画像を見ながら 手動で入力することもできるし、前記文献(5)(特開平6-168317「個人識別装置」）に記載の方法など前記特徴点抽出手段4140で用いたのと同様の様々な方法を利 用可能である。本実施例は人の顔を照合する場合を一例としてあげているが、 例えば多面体形状の物体を照合する場合には頂点が特徴点として利用でき、画 像からエッジを抽出し、それらの交点として多面体の頂点を検出することがで きる。また、物体表面に特徴的な模様がある場合などにその模様の位置を利用 することもできる。

位置姿勢計算手段4222では、前記入力画像特徴点位置と、データ記憶手段4130 から読み出す特徴点位置を利用し、入力画像中にある物体の位置姿勢や撮像装 置のパラメタなどを計算し、位置姿勢として出力する。この計算には前記文献（15）の方法など様々な方法が利用可能であるが、本実施例では一例として位 置姿勢のパラメタとして物体の平行移動距離 (T_x, T_y, T_z)、x, y, z 軸の周 りの回転角度 (R_x, R_y, R_z)、カメラの焦点距離 f を、カメラモデルとして ピンホールカメラを用いて次のような方法をとる。前記のように、焦点距離な ど撮像装置のパラメタも含めて位置姿勢と呼ぶ。特徴点位置 $\vec{A}_i$ と入力 画像特徴点位置 $\vec{B}_i$ の間の関係は［式7］であらわされる。

［式7］

$$\begin{bmatrix} u_i \\ v_i \end{bmatrix} = \frac{f}{c} \begin{bmatrix} a \\ b \end{bmatrix}$$

ただし、ここで a, b, c は［式8］であらわされる値である。

［式8］

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = R \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix}$$

R は［式9］で表される回転を表す行列である。

［式9］

$$R = \begin{bmatrix} \cos R_y \cos R_z & -\cos R_x \sin R_z + \sin R_x \sin R_y \cos R_z & \sin R_z \sin R_x + \cos R_x \sin R_y \cos R_z \\ \cos R_y \sin R_z & \cos R_x \cos R_z + \sin R_x \sin R_y \sin R_z & -\sin R_x \cos R_z + \cos R_x \sin R_y \sin R_z \\ -\sin R_y & \sin R_x \cos R_y & \cos R_x \cos R_y \end{bmatrix}$$

12個の各特徴点についての［式7］で計算される値と入力画像特徴点 位置の値の誤差の総和が最小になるように、$R_x, R_y, R_z, T_x, T_y, T_z, f$ を 最適化計算により求める。この最適化の計算には様々な方法が利用できる。求 めた $R_x, R_y, R_z, T_x, T_y, T_z, f$ を位置姿勢として出力する。

前記の位置姿勢パラメタやカメラモデルの定義と計算方法はあくまで一例であ り、この他にも様々な方法を利用可能である。

照明補正手段4230以下の処理については、第1の実施例と同等である。

次に、本発明の第5の実施例について詳細に説明する。本実施例は 請求項28 および 請求項29 に記載の発明に相当する。

本実施例では、登録される物体が工業製品であり、その形状の設計図がCAD データ として保存されており、表面の塗装の仕様がデザイン図によって決められて いるとする。本実施例は、第1の実施例と比較し、3次元形状測定手段110にお いて、設計図のCADデータから3次元形状を、反射率測定手段120においてデザ イン図から反射率を読み込む点が異なる。

3次元形状測定手段110は、設計図のCADデータを、照合手段200で扱えるデータ 形式に変換して3次元形状として出力する。反射率測定手段120は、デザイン図 から物体の各部の色、表面の仕上げの方法などを読み込み、反射率に変換して 出力する。データ記憶手段130では前記出力された3次元形状と反射率を記憶す る。照合手段200については第1の実施例と全く同等である。

本発明は上記実施例に述べたように一般の物体に対して応用可能であるが、本 発明は特に自動車の車種・型式の照合、人物の顔の照合などの応用にも有効で ある。

以上、本発明を実施例に基づき具体的に説明したが、本発明は前記実施例に限 定されるものではなく、その要旨を逸脱しない範囲において種々変更可能であ ることは言うまでもない。また、本発明をコンピュータプログラムによって実 現することももちろん可能である。

発明の効果

本発明によれば、登録手段でのみ物体の3次元形状と表面の反射率または適当 な照明条件下での画像を計測すればよく、照合手段における撮像手段としては ビデオカメラなどの通常の2次元画像を撮影する撮像装置があるだけで十分で あり、3次元形状測定装置を必要とせず実用的な装置が構成できる。また、3次 元形状が登録されているので、入力画像における物体の3次元的な位置姿勢の 変動に対して完全に補正することができる。また、照明条件の変動に対しても 十分な補正を行うことができる。本発明の照明補正処理は、対象物体の表面の 反射特性が 完全散乱面でないものについても適用でき、物体の他の部分による光源の遮蔽 でできる影やてかりなどに対しても適用できる。したがって方法(8),(9)より もさらに広い範囲の一般的な物体の照合に適用することができる。 また、照明変動画像群を登録されている3次元形状と反射率を用いて自動的に 生成できるため、登録処理において多数の画像を撮影する必要がなく簡便に行 える。また、本発明によれば、照明変動空間の近似として十分な部分空間の次 元数は、累積寄与率を用いて判定することで十分な性能を得ることができる。

図面の簡単な説明

［図1］ は、本発明の画像照合装置の第1の実施例の処理の流れ を示すブロック図、

［図2］ は、本発明の画像照合装置の第1の実施例の構成図、

［図3］ は、本発明の第1の実施例の照明補正処理の処理の流れを示す ブロック図、

［図4］ は、照明条件を決める照明の物体に対する方向を表す角度 を説明する図、

［図5］ は、画像を利用した物体照合装置の例を示した図、

［図6］ は、本発明の第2の実施例の処理の流れを示すブロック図、

［図7］ は、本発明の第2の実施例の照明条件補正処理の流れを示す ブロック図、

［図8］ は、本発明の第3の実施例の処理の流れを示すブロック図、

［図9］ は、平均形状の生成方法を説明する図、

［図10］ は、本発明の第4の実施例の処理の流れを示すブロック図、

［図11］ は、本発明の第4の実施例の位置姿勢推定処理の流れを示す ブロック図、

［図12］ は、対象物体の特徴点として用いる物体の部位の一例を示す図、

［図13］ は、従来の画像照合技術の一例として、登録時と照合時でと もに2次元の画像のみを用いる技術の構成を説明する図、

［図14］ は、従来の画像照合技術の一例として、登録時と照合時でと もに3次元形状を測定する技術の構成を説明する図、

［図15］ は、従来の画像照合技術の一例として、登録時と照合時でと もに2次元の画像を撮影し、位置姿勢の補正に標準3形状を用いる技術の構成を 説明する図、

［図16］ は、従来の画像照合技術の一例として、登録時に多数の位置 姿勢や照明条件で画像を撮影し認識を行う技術の構成を説明する図、

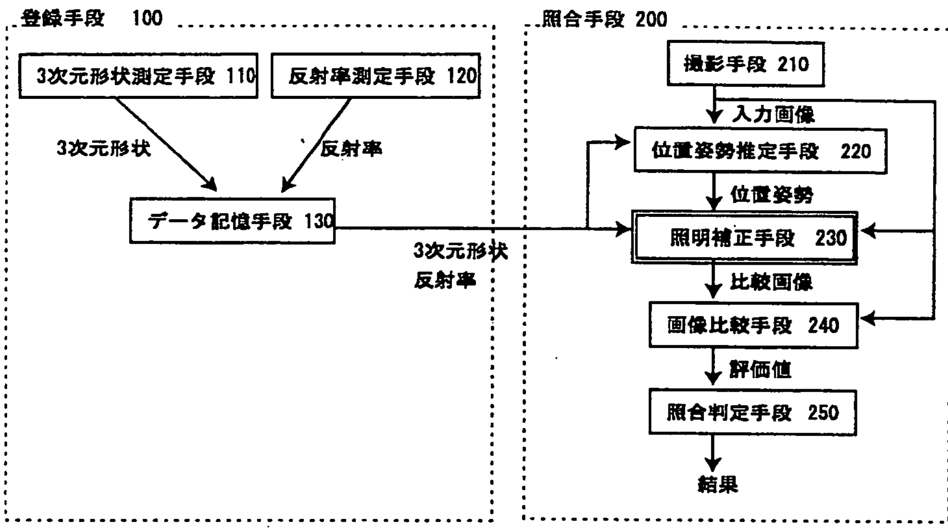
［図17］は、従来の画像照合技術の一例として、登録時に複数の照明 条件で2次元の画像を撮影し照明条件補正を行う技術の構成を説明する図、

［図18］は、従来の画像照合技術の一例として、登録時に多数の照明 条件で2次元の画像を撮影し照明条件補正を行う技術の構成を説明する図、

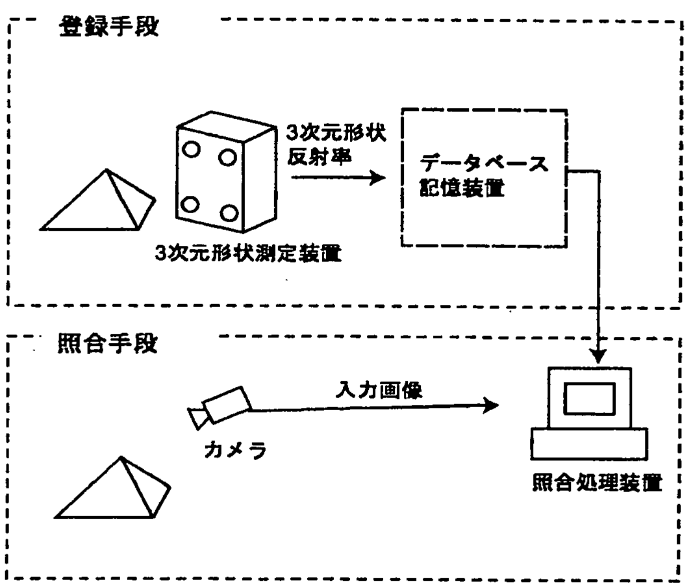
である。

図面

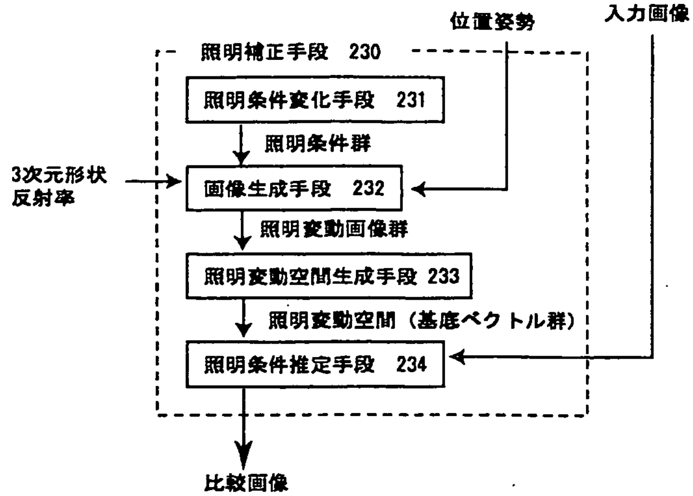
［図1］



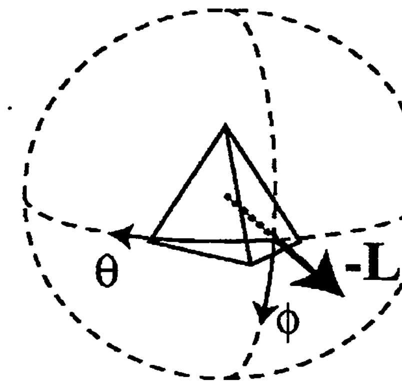
［図2］



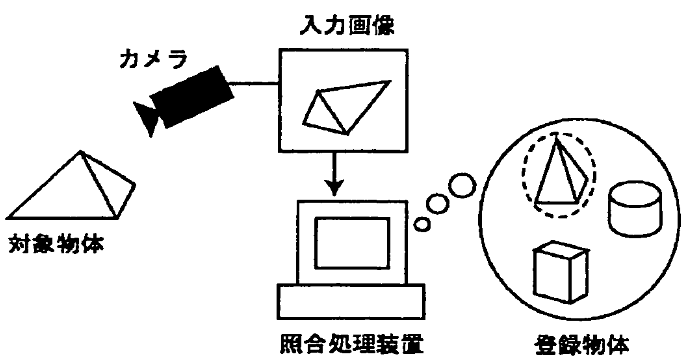
［図3］


位置姿勢
入力画像
照明補正手段 230
照明条件変化手段 231
照明条件群
3次元形状
反射率
画像生成手段 232
照明変動画像群
照明変動空間生成手段 233
照明変動空間（基底ベクトル群）
照明条件推定手段 234
比較画像

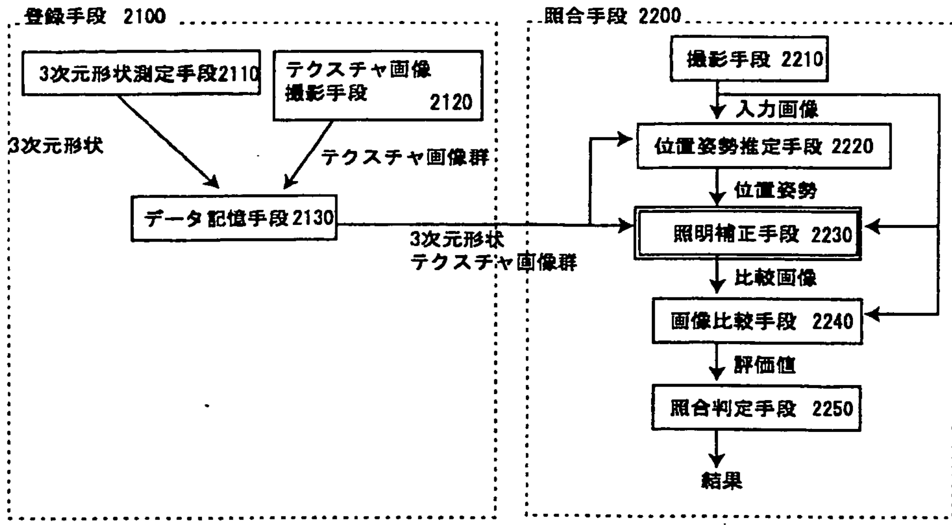
［図4］


θ
-L
ϕ

［図5］

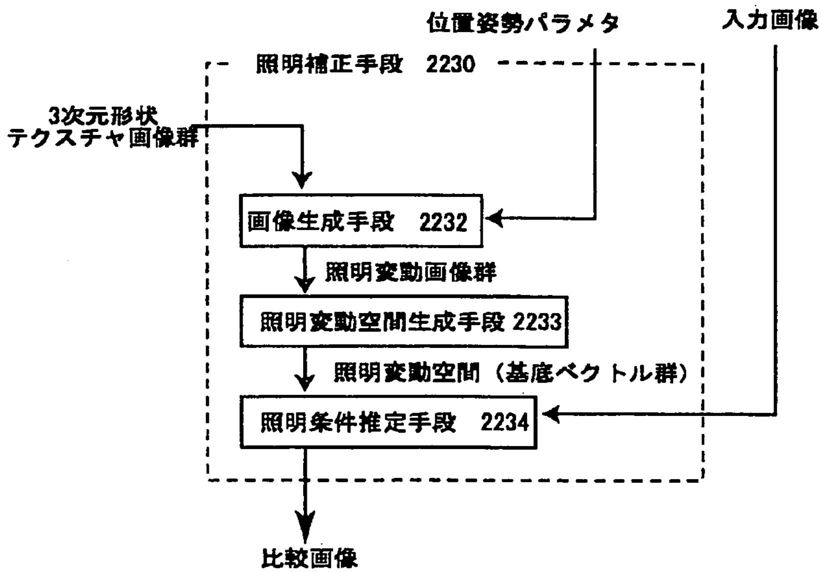

入力画像
カメラ
対象物体
照合処理装置
登録物体

［図6］



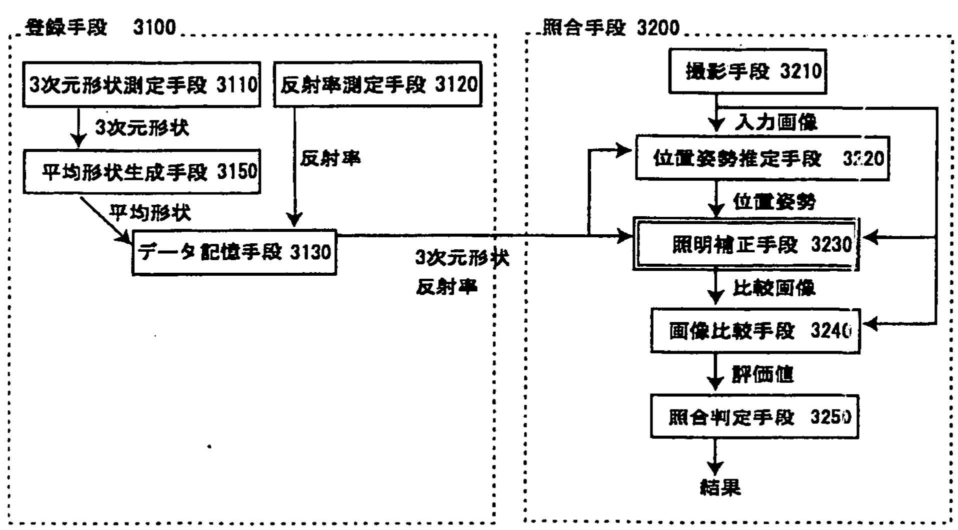
登録手段 2100
3次元形状測定手段2110
テクスチャ画像撮影手段 2120
3次元形状
テクスチャ画像群
データ記憶手段2130
3次元形状
テクスチャ画像群
照合手段 2200
撮影手段 2210
入力画像
位置姿勢推定手段 2220
位置姿勢
照明補正手段 2230
比較画像
画像比較手段 2240
評価値
照合判定手段 2250
結果

[図7]



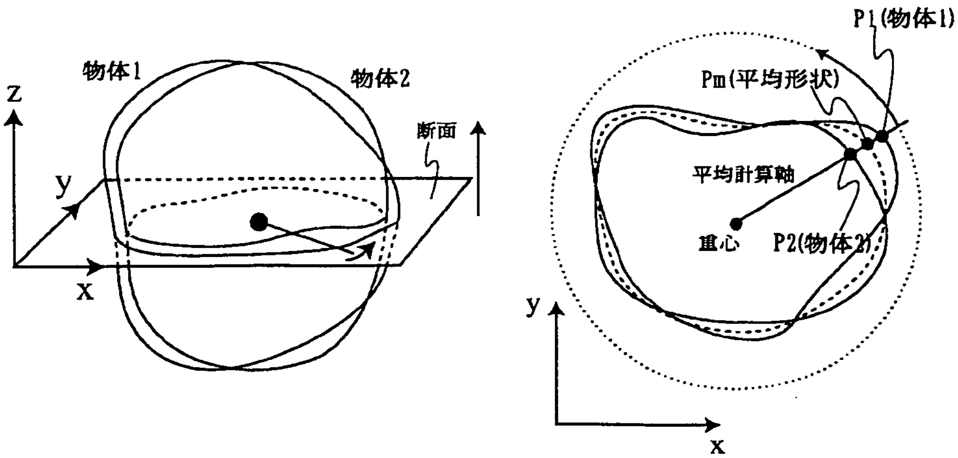
位置姿勢パラメタ
入力画像
照明補正手段 2230
3次元形状
テクスチャ画像群
画像生成手段 2232
照明変動画像群
照明変動空間生成手段 2233
照明変動空間（基底ベクトル群）
照明条件推定手段 2234
比較画像

[図8]

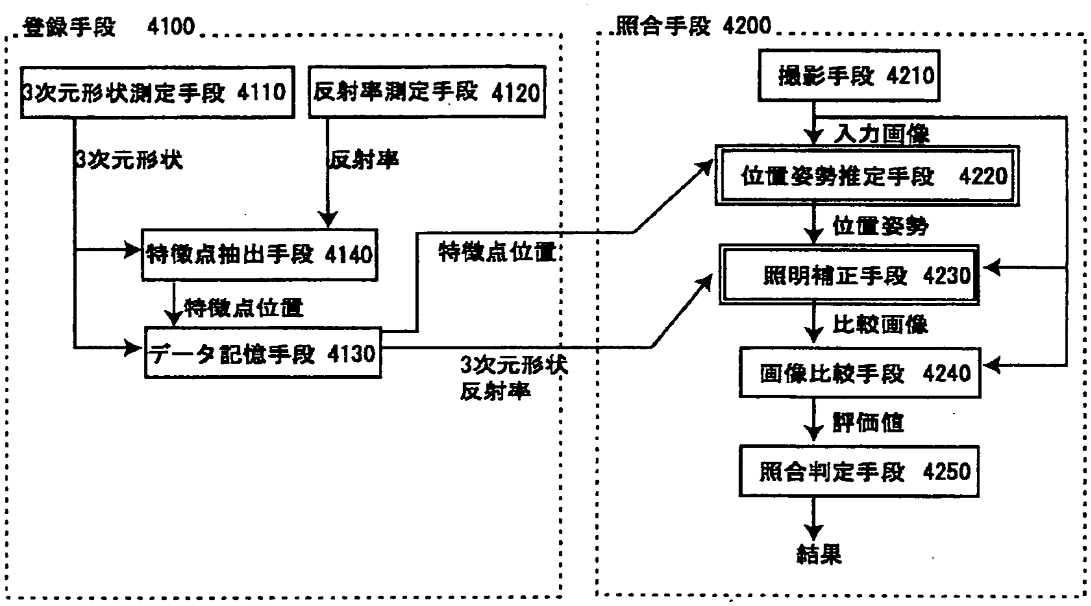


登録手段 3100
3次元形状測定手段 3110
反射率測定手段 3120
3次元形状
平均形状生成手段 3150
反射率
平均形状
データ記憶手段 3130
3次元形状
反射率
照合手段 3200
撮影手段 3210
入力画像
位置姿勢推定手段 3220
位置姿勢
照明補正手段 3230
比較画像
画像比較手段 3240
評価値
照合判定手段 3250
結果

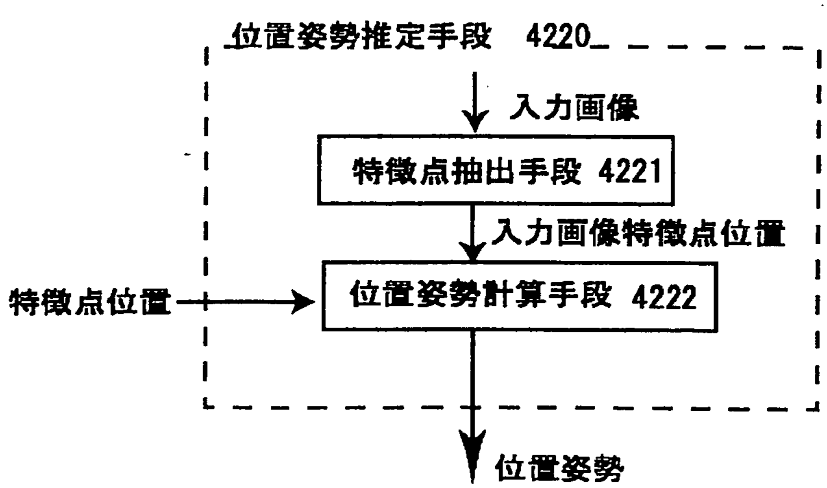
[図9]



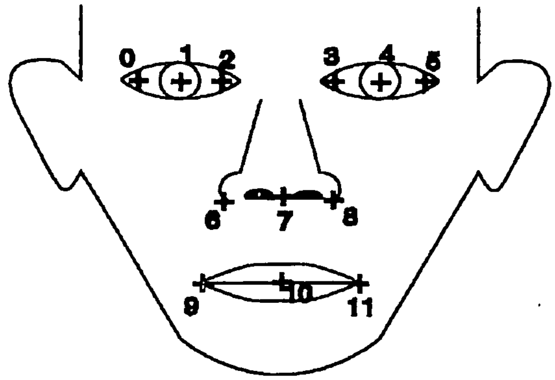
[図10]



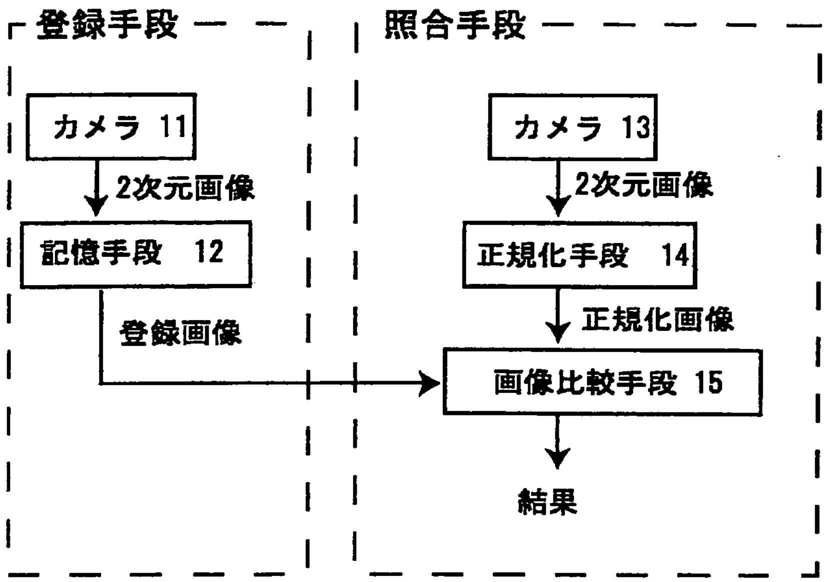
[図11]



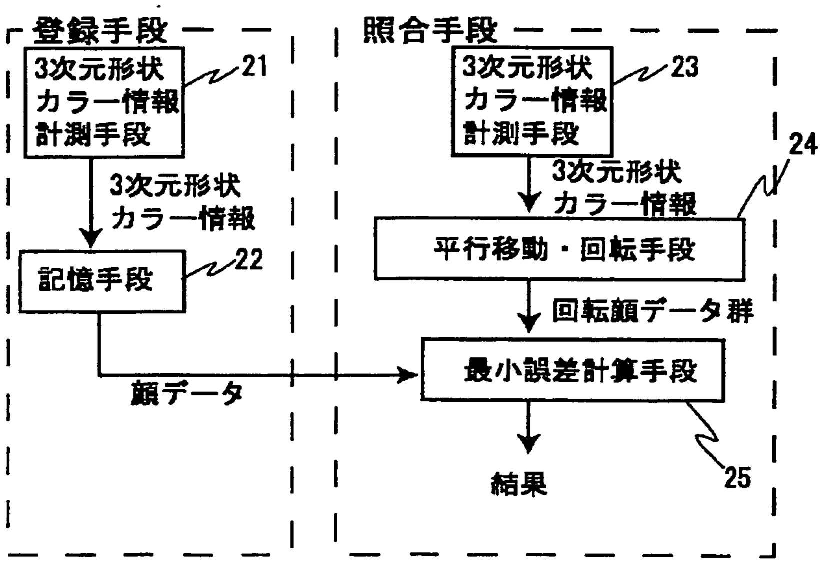
[図12]


0
1
2
3
4
5
6
7
8
9
10
11

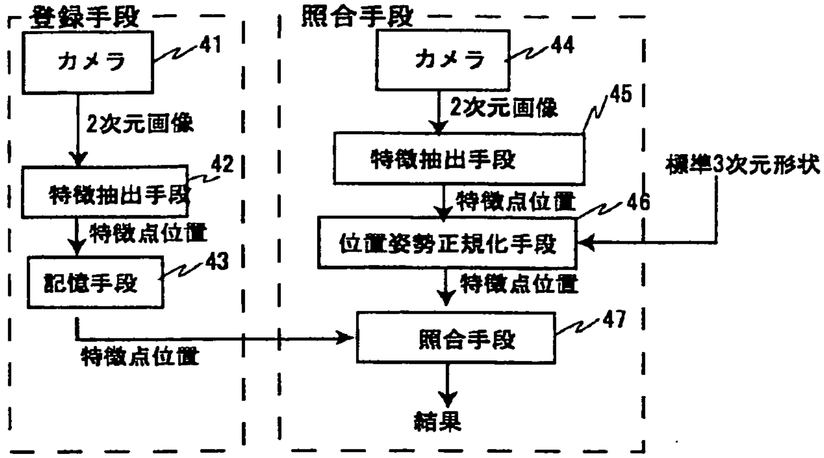
［図13］


登録手段
照合手段
カメラ 11
カメラ 13
2次元画像
2次元画像
記憶手段 12
正規化手段 14
登録画像
正規化画像
画像比較手段 15
結果

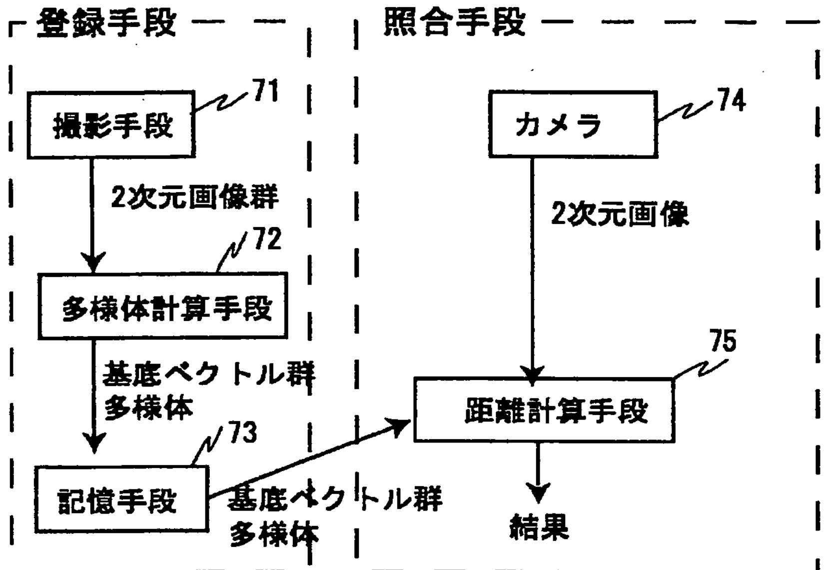
［図14］


登録手段
照合手段
3次元形状
カラー情報
計測手段
21
3次元形状
カラー情報
計測手段
23
3次元形状
カラー情報
24
3次元形状
カラー情報
記憶手段
22
平行移動・回転手段
回転顔データ群
最小誤差計算手段
顔データ
結果
25

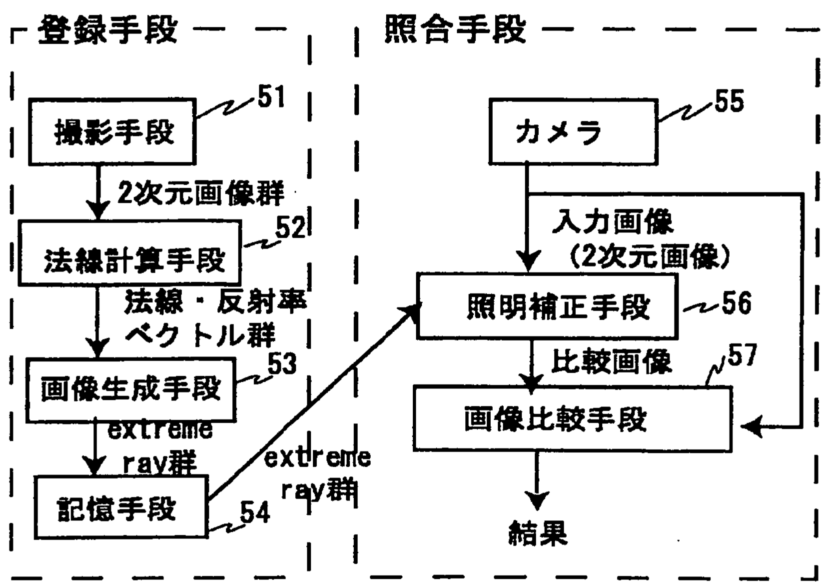
［図15］


登録手段
カメラ
41
2次元画像
特徴抽出手段
42
特徴点位置
記憶手段
43
特徴点位置
照合手段
カメラ
44
2次元画像
45
特徴抽出手段
標準3次元形状
特徴点位置
46
位置姿勢正規化手段
特徴点位置
照合手段
47
結果

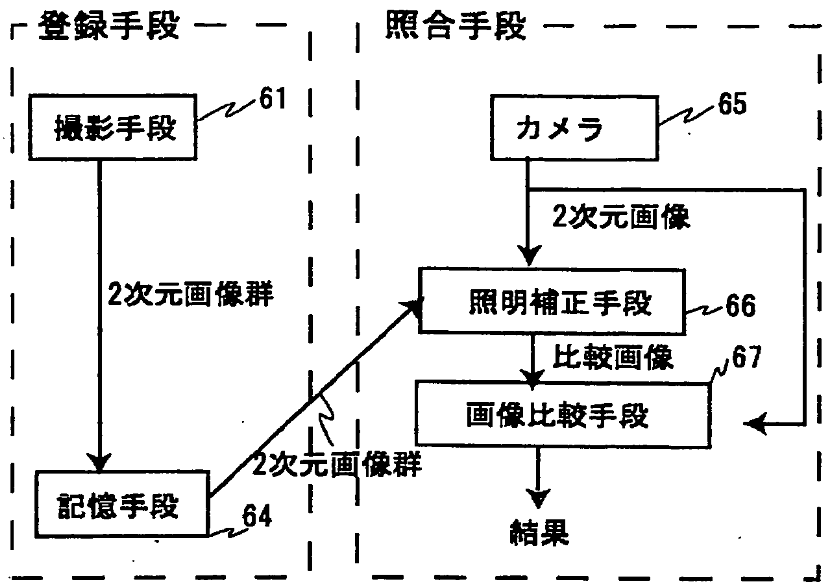
[図16]


登録手段
撮影手段
71
2次元画像群
72
多様体計算手段
基底ベクトル群
多様体
73
記憶手段
基底ベクトル群
多様体
照合手段
カメラ
74
2次元画像
75
距離計算手段
結果

[図17]


登録手段
撮影手段
51
2次元画像群
法線計算手段
52
法線・反射率
ベクトル群
画像生成手段
53
extreme
ray群
記憶手段
54
extreme
ray群
照合手段
カメラ
55
入力画像
（2次元画像）
照明補正手段
56
比較画像
57
画像比較手段
結果

[図18]



書類名

要約書

要約

課題

照合時に3次元形状を測定する必要がなく、様々な位置姿勢や照明条件において カメラなどにより撮影された物体の画像を用いて、登録されている物体であ るかの確認、どの物体であるかの照合、似た物体の検索、などの処理を可能に する画像照合方法、装置、および記憶媒体を提供する。

解決手段

登録手段100は登録する物体の3次元形状と表面の反射率を測定し記憶する。照 合手段200はカメラ等の撮影手段210により入力画像を撮影し、位置姿勢推定手 段220は前記登録された3次元形状と反射率を用いて前記入力画像中の物体の位 置姿勢を推定し、照明補正手段230は前記登録された3次元形状と反射率を用い て前記入力画像と同位置同姿勢、同一照明条件の下での画像を比較画像として 生成し、画像比較手段240は前記比較画像と入力画像の類似度を計算し、照合 判定手段250は該類似度に基づき照合判定を行う。

選択図

[図1]

Title of Document

Specification

Title of Invention

DEVICE, METHOD AND RECORD MEDIUM FOR IMAGE COMPARISON

Scope of Claim for Patent

1. An image comparison method wherein:

in a registration step for registering data of each object to be compared in a database, three-dimensional shape of the object and surface reflectance of the object are measured and stored;

in a comparison step for comparing an input image with the registered data, a two-dimensional image is photographed as an input image by use of video camera, etc., illumination variation images being images of an object in predetermined certain position/pose under various illumination conditions is generated by use of the registered three-dimensional shape and reflectance data, an image being most similar to the input image is obtained from the illumination variation images to be generated as a reference image, and an evaluation value concerning similarity between the reference image and the input image is calculated, and such processes are performed as a verification of whether or not the reference image is the target object, a search for a registered object corresponds to the target object, and a search for a registered object which is similar to the target object.

2. The image comparison method claimed in claim 1, wherein, in the reference image generation step, an illumination variation space being an image space which is spanned by the illumination variation images is generated, and an image which is most similar to the input image in the illumination variation space is generated as a reference image.

3. The image comparison method claimed in claim 2, wherein:

in the illumination variation space generation step, illumination variation space is generated by obtaining the basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting a statistic analysis such as principal component analysis to the illumination variation images; and

in the reference image generation step, correlations are obtained between the basis vectors and the input image , and the reference image that is the most similar to the input image is generated by use of the basis vectors and based on the correlations.

4. The image comparison method claimed in claim 1, wherein:

in the registration step, the illumination variation images are generated beforehand, and the illumination variation images are stored; and

in the comparison step, the registered illumination variation images are used for generating the reference image.

5. The image comparison method claimed in claim 2, wherein, generation of illumination variation images and an illumination variation space in the comparison step is preliminarily performed in the comparison step, the generated illumination variation space is stored in the registration step, and the registered illumination variation space is used for generating the reference image.

6. The image comparison method claimed in claim 3, wherein, generation of illumination variation images and basis vectors in the comparison step is preliminarily performed in the registration step, and the generated basis vectors are stored, and the registered basis vectors are used for generating the reference image in the comparison step.

7. The image comparison method claimed in one of claims 1 to 6, wherein position/pose parameters of the object of the input image are separately inputted instead of employing the predetermined certain position/pose.

8. The image comparison method claimed in one of claims 1 to 6, wherein the position/pose of the object of the input image is estimated by use of the registered three-dimensional shape and reflectance instead of employing the predetermined certain position/pose.

9. The image comparison method claimed in one of claims 1 to 8, wherein, instead of measuring the reflectance, image information is photographed under an adequate illumination to be used as a substitute for the reflectance in the following processes.

10. The image comparison method claimed in one of claims 1 to 8, wherein, in the registration step, the reflectance is measured in such a way that image information under an adequate number of illumination conditions is photographed as texture images, and in the comparison step, for generating the illumination variation images, the texture images are employed instead of changing the illumination conditions.

11. The image comparison method claimed in one of claims 1 to 10, wherein: in the registration step, instead of measuring three-dimensional shapes of plurality of comparison target objects, by measuring one or a few number of three-dimensional shapes, one three-dimensional shape being the one three-dimensional shape or the average of a few number of the three-dimensional shapes is outputted, and thereby, shapes of all target objects are not measured; and

measurement of the reflectance is performed in such a way that the reflectance of all comparison target objects is measured or image information is photographed under one or a plurality of illumination conditions, and only the average shape data as three-dimensional data in the following processes.

12. The image comparison method claimed in one of claims 1 to 11, wherein the three-dimensional shape is not measured and three-dimensional shape is inputted separately from drawings or the like.

13. The image comparison method claimed in one of claims 1 to 12, wherein the reflectance is not measured and reflectance and color information are inputted separately from drawings or the like.

14. The image comparison method claimed in one of claims 1 to 13, wherein, in the registration step, the comparison target object is registered with position information of a feature point.

15. The image comparison method claimed in one of claims 1 to 14, wherein the comparison target object is an automobile.

16. The image comparison method claimed in one of claims 1 to 14, wherein the comparison target object is a human face.

17. An image comparison device wherein:

a registration means for registering data of each object to be compared in a database comprises;

a three-dimensional shape measurement means which measures three-dimensional shape of one or a plurality of comparison target

objects to be registered in a database, and outputs the three-dimensional shape of the objects;

a reflectance measurement means which measures reflectance of surface of each position in three-dimensional shape and outputs the reflectance as reflectance of the object;

a data storage means which stores the three-dimensional data and the reflectance as registered data, and reads out and outputs the data for a comparison process when necessary; and

a comparison means for comparing an input image with the registered data comprises:

a photographing means such as a camera which photographs and outputs an input image;

an illumination condition variation means which sets various illumination conditions and outputs them as illumination conditions;

an image generation means, by being inputted a predetermined certain position/pose and three-dimensional shape and reflectance outputted from the data storage means, generates illumination variation images in the same position/pose as the position/pose under the illumination conditions;

an illumination condition estimation means which obtains an image being most similar to the input image from the illumination variation images and outputs it as a reference image;

an image comparison means which calculates an evaluation value concerning similarity between the input image and the reference image and outputs the evaluation value;

a comparison judgment means which receives the evaluation value, and performs such processes as a verification of whether or not the reference image is the target object, a search for a registered object which corresponds to the target object, and a search for a registered object which is similar to the target object, and outputs the judgment

result.

18. The image comparison device claimed in claim 17, wherein:

the comparison means includes illumination variation space generation means for generating illumination variation space which is spanned by the illumination variation images and outputting the illumination variation space; and

the illumination condition estimation means includes an illumination condition estimation means for generating an image which is most similar to the input image within the illumination variation space as a reference image.

19. The image comparison device claimed in claim 18, wherein:

the illumination variation space generation means generates illumination variation space by obtaining bases vectors of a space that almost accommodates image variation due to the illumination variation by conducting a statistic analysis such as principal component analysis to the illumination variation images; and

the illumination condition estimation means obtains correlations between the basis vectors and the input image, and generates a reference image that is the most similar to the input image by use of the basis vectors and based on the correlations.

20. The image comparison device claimed in claim 17, wherein:

an illumination correction means includes illumination variation space generation means which generates illumination variation space by obtaining bases vectors of a space that almost accommodates image variation due to the illumination variation by conducting a statistic analysis such as principal component analysis to the illumination variation images; and

the illumination condition estimation means obtains correlations between the basis vectors and an input image, and generates a reference image that is the most similar to the input image by use of the basis vectors and based on the correlations.

21. The image comparison device claimed in claim 17, wherein:

the comparison means does not include an illumination variation means or an image generation means;

the illumination condition variation means and an image generation means are included in a registration means;

the storage means stores the illumination variation images; and

the illumination condition estimation means in the comparison means uses the registered illumination variation images.

22. The image comparison device claimed in claim 18, wherein:

the comparison means does not include an illumination condition variation means, an image generation means or an illumination variation space generation means; and

the registration means includes the above three means;

the storage means stores the illumination variation space; and

the illumination condition estimation means in the comparison means uses the registered illumination variation space.

23. the image comparison device claimed in claim 19, wherein:

the comparison means does not have an illumination condition variation means, an image generation means or an illumination variation space generation means;

the registration means includes the above three means;

the storage means stores the basis vectors; and

the illumination condition estimation means in the comparison

means uses the registered basis vectors.

24. The image comparison device claimed in one of claims 17 to 6, wherein:

a position/pose input means which separately inputs position/pose parameters of an object in the input image instead of employing the predetermined certain position/pose is added; and

the illumination correction means uses the input position/pose.

25. The image comparison device claimed in one of claims 17 to 6, wherein:

a position/pose estimation means which receives the input image outputted from the photographing means, and estimates the position/pose of the object in the image, and subsequently outputs the position/pose is added; and

the illumination correction means uses the estimated position/pose.

26. The image comparison device claimed in one of claims 17 to 24, wherein a reflectance measurement means in the registration means is an image photographing means which obtains image information by setting adequate illumination and outputs the image information as a reflectance, and a plurality of the image information is used as a subsequent of the reflectance.

27. The image comparison device claimed in one of claims 17 to 24, wherein the reflectance measurement means in the registration means is an image photographing means which obtains image information by setting adequate number of illumination conditions, and outputs a plurality of the obtained image information as texture images; and

there is no illumination condition variation means in a comparison

step; and

the image generation means generates images by use of the texture images instead of varying illumination conditions.

28. The image comparison device claimed in one of claims 17 to 24, wherein the registration means includes an average shape generation means which receives inputted one or a few three-dimensional shapes, and outputs the three-dimensional shape or one average shape of the few three-dimensional shapes;

the data storage means stores only the generated average shape; and the comparison means uses the average shape.

29. The image comparison device claimed in one of claims 17 to 27, wherein there is no three-dimensional measurement means and the three-dimensional shape is separately inputted from drawings or the like.

30. The image comparison device claimed in one of claims 17 to 25 and 11 to 12, wherein there is no reflectance measurement means and the reflectance is inputted separately from drawings or the like.

31. The image comparison device claimed in one of claims 17 to 27, wherein:

the registration means further includes feature point extraction means for adding, in the registration step, to the registered data, feature point position information which is information about positions having feature appearance of the comparison target object as a necessary information for estimating the position/pose.

32. In the image comparison device claimed in one of claims 17 to 30,

an automobile image comparison device wherein the comparison target object is an automobile.

33. In the image comparison device claimed in one of claims 17 to 30, a human face image comparison device wherein the comparison target object is a human face.

34. The image comparison device claimed in one of claims 17 to 32, wherein, as a photographing means for obtaining an input image, an image input device is employed for reading films, photos, documents and the like.

I do not describe claims for a record medium, I would appreciate it if you could compensate for them, thank you.

Detailed Description of the Invention

Field of the Invention

The present invention relates to a comparison technique of objects, and in particular, to an image comparison device, an image comparison method and record medium which makes a data processing device execute the image comparison, in which three-dimensional shape, surface reflectance, color information and the like are preliminarily registered, it is possible to conduct comparison correctly withstanding variations of shooting conditions such as position/pose of the target object in the image and illumination conditions.

Prior Art

As shown in Fig.5, image comparison techniques are such techniques that an object existing in the three-dimensional space in a random position/pose is photographed to acquire one or more input images by use

of a photographing device such as camera or video camera. Thereafter, the input images of the target object are compared with images of objects which have preliminarily been registered. The image comparison process is generally composed of two steps: a registration step for registering and storing the compared objects; and a comparison step for comparing the input image of the target object with the registered data of the registered objects and thereby judging what the target object is. In each step, the photographed image is used as a two-dimensional image without being processed, or is used after being converted to a three-dimensional shape by means of the technique disclosed in Document 1: “3D image measurement”, Iguchi, Sato, SHOKODO. In the following, conventional image comparison techniques will be explained in detail with reference to documents.

As an example of an image comparison technique in which two-dimensional images are registered beforehand and a two-dimensional image is used as an input image, there is disclosed in Document 2: "face image comparison device" in Japanese Patent No.2872776. This prior art has been designed to conduct image comparison of human faces and has such configuration as shown in Figs. 1 and 3. In the registration step, two-dimensional images are obtained by use of a camera 11, and the obtained two-dimensional images are stored in a storage means 12. In the comparison step, a two-dimensional face image is obtained as the input image by use of a camera 13. A normalization means 14 extracts feature points being eyes, nose, etc. to be used as the criteria for judging pose, size, etc. from the input image by means of image processing. A normalized image which is normalized in accordance with two-dimensional position and size on an image is outputted by use of the feature points as coordinates position. Thereafter, an image comparison means 15 compares

registered images reads out from the storage means 12 with the normalized image by means of pattern recognition, and outputs the result of the comparison.

As an example of a conventional comparison technique using three-dimensional shapes, there is disclosed in Document 3: a "personal identification device" in Japanese Patent Application Laid-Open No.HEI9-259271. In this prior art, there is configured as shown in Fig. 14. In the registration step, a three-dimensional shape color measurement means 21 measures three-dimensional shape and color of each comparison target object, and the three-dimensional shape information and the color information are stored in a storage means 22. In the comparison step, a three-dimensional shape color measurement means 23 measures three-dimensional shape and color of a target object as input data. A translation/rotation means 24 translates the input data so that the barycenter of the input data will be on the barycenter of the registered data. Subsequently, the translation/rotation section 24 rotates the translated input data in various ways, and a minimum error calculation means 25 obtains the error between the rotated input data and the registered data. The minimum error calculation means 25 adjusts the three-dimensional position and pose of the input data. Thereafter, the minimum error calculation section 25 compares the corrected data with the registered data.

A "personal identification device" disclosed in Document 5: Japanese Patent Application Laid-Open No.HEI6-168317 uses two-dimensional images both in the registration step and the comparison step, and the configuration thereof is as shown in Fig. 15. In the registration step, two-dimensional images are obtained by use of a camera 41. A feature extraction means 42 extracts feature points where variations in pixel

intensity are large and stores position data of the feature points in a storage means 43. In the comparison step, a two-dimensional image is obtained as an input image by use of a camera 44. Subsequently, a feature extraction section 45 extracts feature points where variations in pixel intensity are large from the two-dimensional input image and outputs position data of the feature points. Subsequently, the comparison means 47 conducts the personal identification by comparing the registered feature point position and the feature position of the input image. Here, in order to compensate for and absorb variations in position/pose of the target object, the feature point position data outputted by the feature extraction means 45 is normalized by a position/pose normalization means 46 by use of a three-dimensional shape model of a standard object which has been prepared in the position/pose normalization means 46.

A technique disclosed in a Document 6: Hiroshi Murase and Shree K. Nayer "Visual Learning and Recognition of three-dimensional objects from Appearance", Int. J. Computer Vision, vol.14, pp.5-24 (1995) uses only two-dimensional images both in the registration step and the comparison step and executes correction not only for variations in position/pose but also for variations due to illumination conditions. Fig. 16 shows the configuration of the conventional art. In the registration step, a large set of sample images of each object are obtained by a photographing means 71 by automatically varying pose of the object and illumination conditions so that all feasible poses and illumination conditions can be covered. A manifold calculation means 72 obtains basis images capable of expressing the variations of the sample images, by means of principal component analysis. Subsequently, the manifold calculation section 72 generates a feature space which is spanned by the basis images, obtains a trajectory of the sample images in the feature

space as a manifold, and stores the obtained manifold in a storage section 73. In the comparison step, a two-dimensional image of a target object is obtained by a camera 74 as an input image. A distance calculation means 75 calculates the distance between the input image and the manifold in the feature space and executes the comparison using the distance as a yardstick. Thereby, the comparison by use of the input image, which can be obtained under various illumination conditions and poses, is made possible.

Changes occurring to a two-dimensional image due to variations of illumination conditions when the position/pose of the object is fixed has been analyzed in detail in a Document 7: Peter N. Belhumeur and David J. Kriegman "What is the Set of Images of an Object Under All Possible Illumination Conditions ?", Int. J. Computer Vision, vol.28, pp.245-260 (1998). In the case where the position and pose of the object are fixed, an image obtained under an arbitrary illumination condition can be resolved into images each of which is obtained under a point source of light. Therefore, an image obtained under an arbitrary number of point sources of light can be expressed as a linear combination of images each of which is obtained under a point source of light, in which the intensity of each point source is used as each coefficient of the linear combination. Based on the above analysis, a method called "illumination subspace method" which is shown in Fig. 17 has been proposed.

Based on the above analysis, in the Document 7, there is suggested a method structured as shown in Fig. 17, called "Illumination Subspace Method (hereinafter referred to as method (8))". A photographing means 51 selects and sets three or more illumination conditions so that the number of pixels in shadow will be as small as possible, and obtains images under the three or more illumination conditions. A normal line

calculation means 52 obtains reflectance vectors on the surface of the object, with regard to each pixel in the images, by means of principal component analysis. An image generation means 53 successively generates images which are called "extreme rays" and stores the generated extreme rays in a storage means 54. In the comparison step, a two-dimensional image of a target object is obtained by use of a camera 55 as an input image. When the reflectance property of the surface of an object is perfect scattering and the surface is convex, an image of the object under an arbitrary illumination condition can be expressed by a linear combination of the extreme rays with positive coefficients, and therefore, an illumination correction means 56 generates a reference image being an image of the registered object under the same illumination condition as in the input image by use of a linear combination of the extreme rays. The coefficients of the linear combination are determined by use of the nonnegative least-squares method. An image comparison means 57 compares the input image with the reference image by calculating the similarity between the two images.

In a technique disclosed in a Document 10: A. S. Georghiades et al. "Illumination Cones for Recognition Under Variable Lighting: Faces", Proc. IEEE Int. Conf. CVPR, pp.52-58 (1998), when the extreme rays are obtained according to the method (8), pixels that should be in shadow are found out based on the three-dimensional shape of the object by use of techniques of computer graphics such as ray tracing, and the pixels are shadowed. The technique of this document aims to apply the method (8) to objects having concavities.

The aforementioned Document 7 also proposes a Sampling Method (hereinafter referred to as method (9)), which is shown in Fig. 18. It

takes much time to calculate all the extreme rays as in the method (8), and therefore, a photographing means 61 in the registration step selects and sets an appropriate number of illumination directions so that the angles (θ, ϕ) shown in Fig. 4 will cover the sphere at almost even intervals for example, and obtains images. The images obtained as above are substituted for the extreme rays. Thereafter, in the same way as the method (8), the illumination correction is executed by means of the nonnegative least-squares method and thereafter the object recognition is executed.

Problems that the Invention is to Solve

The target object in front of a photographing device being camera, video camera, etc., generally moves in the three-dimensional space (parallel translation, rotation, etc.) unless the position/pose of the target object is fixed or adjusted. Further, the illumination conditions vary every moment when the photographing of the target object is done outdoors. Therefore, the appearance of the two-dimensional input image of the target object is necessitated to vary widely. The conventional techniques could not compensate for and absorb enough the variations in the position/pose of the target object and the illumination conditions, thereby the application of the conventional image comparison techniques used to be confined within narrow limits. In the following, the problems in the conventional techniques of the above documents will be described in detail.

The comparison technique as disclosed in Document 2 employing the simple image comparison between two-dimensional images can not cope with variations of appearance in two-dimensional images caused by changes of the pose of the target object being three-dimensional rotation, etc., illumination conditions, etc. Therefore, the application of the

technique of the Document 2 is extremely limited.

The image comparison technique disclosed in Document 3 requires three-dimensional shapes not only in the registration step but also in the comparison step. A three-dimensional shape measurement device described in Document 1 becomes necessary on each comparison, and thus, the cost for the comparison is necessitated to be high, especially when the measurement of the target object has to be done away from the place where the registration step has performed. Further, for the measurement of the three-dimensional shape, each object has to stand still until the measurement is completed, and a darkroom etc. becomes necessary for obtaining precise data. Therefore, the application of the technique of the Document 3 is also limited.

The technique employed in the Document 5, which detects pixel positions where variations in intensity are large, is effective for comparing objects such as blocks having large three-dimensional curvatures, black marks on a white board having steep change of reflectance, etc. However, the technique is not suitable for comparison of human faces as mentioned in the Document 5, which means that stable and reliable detection of the feature points is difficult. The Document 5 also refers to a correction of pose by use of a standard three-dimensional shape of target objects, however, the method can not be employed unless the objects are similar in shape.

In the technique disclosed in the Document 6, enormous amount of two-dimensional sample images have to be gathered, taking the possibilities of various illumination conditions (two or more point sources, extra lights other than point sources, etc.) into consideration. Further, the shape of the manifold in the feature space is not defined at all,

therefore, it is difficult to find appropriate sets of parameters when the distance between the input image and the manifold is calculated in the feature space. Therefore, large amounts of calculations are necessary.

The methods (8) and (9) require images of the registered object illuminated from many directions. A specially designed lighting unit has to be used in the registration step, and precise setting of the illumination conditions is difficult from the viewpoints of placement and setting of equipment. Further, in the method (8) and (9), if the position or pose of an object changed, images of the object in the new pose have to be obtained again under a lot of illumination conditions, and the calculations have to be done all over again. Therefore, in the registration step, a huge amount of images of the registered object in various feasible poses have to be obtained under a lot of illumination conditions, taking much time and manpower. If the target object is photographed in the comparison step in a different pose, the comparison becomes impossible.

Moreover, the technique of the method (8) requires large amounts of calculation for obtaining the extreme rays, depending on the complexity of the shape. According to the Document 7, when there are m independent normal vectors on the surface of the object, the number of the extreme rays amounts to $m(m-1)$ at the maximum. Therefore, an enormous amount of extreme rays have to be calculated unless the shape of the object is very simple as a block. Therefore, it is very difficult to calculate all the extreme rays for ordinary objects having complex shapes. Further, the method can not be directly applied to cases where the object has a concavity, and thereby, a cast shadow occurs.

In the technique of the method (9), the amount of calculations in the

nonnegative least-squares method also tends to be enormous depending on the number of extreme rays. In addition to the above problems, the sampling method also has a problem that it is not clear how many basis images are necessary for obtaining satisfactory result and performance.

Further, both the methods (8) and (9) have been constructed assuming that the surface reflectance property of each object is perfect scattering. Therefore, the methods can not be applied directly to cases where mirror reflection exists or cases where the surface reflectance property is diffusion reflection but not perfect scattering. The majority of ordinary objects do not exhibit the surface perfect scattering.

Object of the Invention

The objects of the present invention is to provide a method, device and a record medium for image comparison, wherein:

first, as an input image used for comparison, a two-dimensional image obtained by an ordinary camera can be employed;

second, the three-dimensional changes of the position/pose of an object in the input image can be corrected;

third, necessary data can be easily measured in the registration step; and

fourth, the correction of illumination conditions can be conducted with regard to the input image which is obtained under various illumination conditions at high processing speed.

Means of Solving the Problems

In accordance with a first aspect of the present invention, in a registration step for registering data of each person to be compared in a database, three-dimensional shape of the object and surface reflectance of the object are measured and stored. In a comparison step for

comparing an input image with the registered data, a two-dimensional image is photographed as an input image by use of video camera, etc. Thereby, illumination variation images being images of an object in predetermined certain position/pose under various illumination conditions by use of the registered three-dimensional shape and reflectance data, an image being most similar to the input image from the illumination variation images is obtained to be generated as a reference image, and an evaluation value concerning similarity between the reference image and the input image is calculated, and such processes are performed as a verification of whether or not the reference image is the target object, a search for a registered object corresponds to the target object, and a search for a registered object which is similar to the target object.

In accordance with a second aspect of the present invention, in the first aspect, in the reference image generation step, an illumination variation space being an image space which is spanned by the illumination variation images is generated, and an image which is most similar to the input image in the illumination variation space is generated as a reference image.

In accordance with a third aspect of the present invention, in the second aspect, in the illumination variation space generation step, an illumination variation space is generated by obtaining the basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting a statistic analysis such as principal component analysis to the illumination variation images, and in the reference image generation step, correlations are obtained between the basis vectors and the input image , and the reference image that is the most similar to the input image is generated by use of the

basis vectors and based on the correlations.

In accordance with a fourth aspect of the present invention, in the first aspect, in the registration step, the illumination variation images are preliminarily generated, and the illumination variation images are stored, and in the comparison step, the registered illumination variation images are used for generating the reference image.

In accordance with a fifth aspect of the present invention, in the second aspect, generation of illumination variation images and an illumination variation space in the comparison step is preliminarily performed in the registration step, and the generated illumination variation space is stored, and the registered illumination variation space is used for generating the reference image in the comparison step.

In accordance with a sixth aspect of the present invention, in the third aspect, generation of illumination variation images and basis vectors in the comparison step is preliminarily performed in the registration step, and the generated basis vectors are stored, and the registered basis vectors are used for generating the reference image in the comparison step.

In accordance with a seventh aspect of the present invention, in one of the first to third aspects, position/pose parameters of the object of the input image are separately inputted instead of employing the predetermined certain position/pose.

In accordance with a eighth aspect of the present invention, in one of the first to third aspects, the position/pose of the object of the input image is estimated by use of the registered three-dimensional shape and

reflectance instead of employing the predetermined certain position/pose.

In accordance with a ninth aspect of the present invention, in one of the first to eighth aspects, instead of measuring the reflectance in the registration step, image information is photographed under an adequate illumination to be used as a substitute for the reflectance in the following processes.

That is, in the ninth aspect of the present invention, an image photographed under an adequate illumination condition can be substituted for the surface reflectance of the object. For example, there is employed the fact that an image being photographed under such illumination conditions where the object is illuminated uniformly and any shadow is hardly cast, its intensity value is considered to be substantially in proportion to its reflectance.

As an example of a method capable of being implemented to an image photographing means substituted for the reflectance measurement means, a following method is present. A hemispherical scaffold is set up in front of the object to be registered and an adequate number of illumination lamps are fixed to the scaffold. An image is photographed with all lamps being turned on at the same time. Other than this method, there are various methods as to employing one or more reflectors in order to diffuse light and illuminate the object uniformly.

In accordance with the tenth aspect of the present invention, the reflectance measurement in the registration step in one of the first to eighth aspects is replaced by photographing texture images under an adequate number of illumination conditions being set so as to be equivalent to illumination conditions set in an illumination condition

variation process. Further, instead of varying the illumination conditions in the generation step of the illumination variation images in one of the first to eighth aspects, employing each image of the texture images to generate an illumination variation image. Moreover, other than the above changed points, processes are same as those of the first to eighth aspects.

That is, in accordance with the tenth aspect, there is set an adequate number of illumination conditions for generating enough sample images for generating illumination variation spaces including the variation of the image of the comparison target object due to the illumination conditions. By photographing image information under the illumination conditions, it is possible to generate sample images for generating illumination variation space without the need of the reflectance measurement, illumination condition setting in the CG image generation, shadow generation by means of ray tracing, etc.

As an example of a method which can be applied to a photographing process of texture images, there is the following method. A hemispherical scaffold is set up in front of the object to be registered and an adequate number of illumination lamps are fixed to the scaffold at even intervals. The object is photographed repeatedly by successively turning each lamp on. It is also possible to photograph the object repeatedly moving a lamp by a manipulator and turning the lamp on repeatedly.

The photographed texture images are registered and stored together with the three-dimensional shape data as the registered data. The comparison step is conducted without executing the illumination condition variation process. Instead of the illumination condition

variation process, the stored texture images are successively read out and an image of the registered object in the position/pose estimated by the position/pose estimation process is generated by means of computer graphics so that intensity values on the surface of the object in the generated image will be the same as those of the texture images. The generated image is outputted as the sample image. The following processes are same as those of one of the first to eighth aspects of the present invention.

In accordance with a eleventh aspect of the present invention, in one of the first to tenth aspects, in the registration step, instead of measuring three-dimensional shapes of plurality of comparison target objects, by measuring one or a few number of three-dimensional shapes, one three-dimensional shape being the one three-dimensional shape or the average of a few number of the three-dimensional shapes is outputted, and thereby, shapes of all target objects are not measured, and measurement of the reflectance is performed in such a way that the reflectance of all comparison target objects is measured or image information is photographed under one or a plurality of illumination conditions, and only the average shape data as three-dimensional data in the following processes.

That is, in accordance with the eleventh aspect of the present invention, the position/pose estimation process and the illumination correction process can be performed by use of the representative three-dimensional shape data instead of measuring and using the three-dimensional shapes of all objects in the case where the shapes of the objects are similar to each other.

The following method is used as an example of a method which is

adaptable to the generation of an average three-dimensional shape. Here, a description will be given of an example for obtaining an average shape of two objects. The three-dimensional shapes of an object 1 and an object 2. The three-dimensional shape data of the registered object 1 or 2 is translated so that the barycenters of the objects 1 and 2 will overlap one another as shown in a left diagram in Fig. 9, and sections that are perpendicular to the z-axis at appropriate intervals are set, and average shapes on each of the sections are calculated. As shown in a right diagram in Fig. 9, a line being average calculation line is drawn outward from the barycenter of the object on the section, and intersection points P_1 and P_2 of the average calculation line with shapes of the objects 1 and 2 are obtained. The three-dimensional coordinates of a point P_m of the average shape are obtained by averaging three-dimensional coordinates (x_1, y_1, z_1) and (x_2, y_2, z_2) of the surface points P_1 and P_2 as expressed by $\left(\frac{x_1+x_2}{2}, \frac{y_1+y_2}{2}, \frac{z_1+z_2}{2}\right)$. By performing the above process by repeating the above calculation around the barycenter at proper intervals, the average shape of the objects 1 and 2 can be generated. Thereby, in the three-dimensional shape measurement process, the generated average shape can be outputted.

This method can be adopted to the case where the number of the objects is more than three. Further, various other method can also be employed to obtain the average shape.

In the following, in a process in a comparison step, the average shape is read out from the data storage process and substitutes for the three-dimensional shape of each object.

In accordance with a twelfth aspect of the present invention, in one

of the first to eleventh aspects, the image comparison method does not include the three-dimensional measurement process and the three-dimensional shape is separately inputted from drawings and the like.

That is, in the twelfth aspect of the present invention, as an example, in cases where the three-dimensional shape measurement by use of an ordinary three-dimensional shape measurement device is difficult and actually making a survey or measurement is necessary, for example the case where the comparison target object is an industrial product with a design drawing, a house, a building, etc., it is possible to input the three-dimensional shape of an object from drawings and the like.

In accordance with a thirteenth aspect of the present invention, in the image comparison method in one of the first to eleventh aspects, the reflectance is not measured and reflectance is inputted separately from drawings and the like.

That is, in the thirteenth aspect of the present invention, as an example, in the case where the comparison target object whose surface reflectance of each position on the painted surface of the object such as industrial products is known, the three-dimensional shape of the object can be inputted from drawings and the like.

In accordance with the fourteenth aspect of the present invention, in the image comparison method described in one of the first to thirteenth aspects, as information necessary for performing a position/pose estimation process, position information of a feature point of the comparison target object is added to the registered data, in the registration step.

That is, in accordance with the fourteenth aspect of the present invention, there is employed the fact that positions of the feature points of the comparison target object in the input image are extracted, and the three-dimensional coordinates of the feature points can be obtained from the registered data, and thereby, position/pose parameters of the object in the input image and photographing device parameters can automatically be obtained by use of the positions of the feature points on the image and the three-dimensional coordinates.

As a method for automatically obtaining the parameters concerning the position/pose and the photographing device when positions of points in an image and three-dimensional coordinates of the points are known, a camera calibration method can be used. There are various methods of the camera calibration method, and as an example thereof, the method in Document 15: Roger Y. Tsai "An Efficient and Accurate Camera Calibration Technique for 3D Machine Vision", Proc. CVPR '86, pp364-374 (1986), can be employed. A detailed description thereof is omitted here.

Embodiments of the Invention

The present invention employs the following principles that an image of an object in an arbitrary position/pose under an arbitrary illumination condition can be generated by preliminarily registering the three-dimensional shape and surface reflectance of the object, and a set of images of the object in the position/pose under various illumination conditions can be expressed as a low-dimensional subspace of the image space.

A description will be given of a position/pose estimation process. In

the position/pose estimation process, there is estimated photographing conditions such as parameters of position/pose of the object and photographing device at the time when the input image was photographed. As the position/pose estimation process, various methods which are performed automatically or manually can be employed.

For example, such method can be employed as manually performed method that when the input image and an image generated by using computer graphics (hereinafter referred to as CD image) from the three-dimensional shape of the comparison target object and reflectance thereof are overlapped, both images are overlapped as exactly as possible by employing an interactive interface by which position/pose parameters can be adjusted or inputted.

As a method for performing estimation of position/pose, there can be employed the method in which CG images of the comparison target object in various positions/poses are successively generated, and the CG images are compared with the input image, and a CG image that matches the input image the best is selected and thereby the parameters of position/pose and the photographing device can be obtained.

Further, instead of comparing images, the position of the points or areas having features (hereinafter referred to as feature points) where intensity changes steeply etc. on an image is detected in the input image and CG images, and thereby, parameters concerning the position/pose and the photographing device are calculated by selecting a CG image whose feature point positions are the nearest to those of the input image.

It is also possible to determine the position/pose of the target object by use of the relationship between the feature point positions in the

input image. In Document 13: Shinn-Ying Ho and Hui-Ling Huang "An analytic solution for the pose determination of human faces from a monocular image", Pattern Recognition Letters, Vol.19, pp.1045-1054 (1998), feature points such as the tails of eyes and the ends of lips are used when human faces are used as a comparison target object, and the position/pose of an object is determined by use of the relationship between the feature points such that a line connecting two eye-feature points is parallel to a line connecting two mouth-feature points, etc.

As the fourteenth aspect of the present invention, by registering the positions of the feature points of the object, the method of the camera calibration can be used. There are various methods of the camera calibration method, and as an example thereof, the method in Document 15: Roger Y. Tsai "An Efficient and Accurate Camera Calibration Technique for 3D Machine Vision", Proc. CVPR '86, pp364-374 (1986), can be employed.

Next, a description will be given of an illumination correction process.

Assuming that the reflectance property on the surface of the object is perfect scattering and the surface is convex with no shadow caused by light occlusion by other parts and the light source exists at an infinite-point, the intensity value $I(u, v)$ of each pixel (u, v) of an image can be expressed as the following [Equation 1], by use of the reflectance $B(u, v)$ and a normal vector $\vec{N}$ (u, v) corresponding to the pixel (u, v) and the intensity Ii and a direction vector $\vec{L_i}$:

[Equation 1]

$$I(u,v)=B(u,v)\max\left(\sum_i\left(l_i\vec{L}_i\cdot\vec{N}(u,v)\right),0\right)$$

Here, if we neglect the effect of the "*max 0*", an arbitrary illumination condition including cases where a plurality of lamps are used can be expressed by only one illumination vector $\vec{L}$ as follows:
[Equation 2]

$$I(u,v)=B(u,v)\vec{N}(u,v)\cdot\vec{L}\left(\vec{L}=\sum_i l_i\vec{L}_i\right)$$

The degree of freedom of images of the object generated by the illumination variation is equal to the number of dimension of the illumination vector $\vec{L}$, that is, 3 or less. However, the degree of freedom actually becomes higher due to the effects of the "*max 0*", cast shadow occurring on the surface of the object due to light occlusion by other parts, imperfect scattering on the surface, etc. However, most of the images lie in or lie sufficiently close to a three-dimensional subspace. Therefore, actually occurring image variation can be approximated as a low-dimensional subspace. The low-dimensional subspace will be hereinafter referred to as an "illumination variation space" of each object.

The principal component analysis is used for obtaining basis vectors of the illumination variation space. A plurality of images of the target object generated by the illumination variation (hereinafter, referred to as "illumination variation images") are prepared, and a set being composed of all the images generated by the variation of illumination condition is approximated. Each of the illumination variation images is generated as an image under illumination of a single point source of light at an infinite-point. A plurality of illumination variation images are prepared

by setting and changing the direction of the point source of light at appropriate intervals so that all possible directions of the point sources in the photographing of the input image can be covered. An image obtained under plurality of illumination lamps can be expressed as the sum of images obtained under each single illumination lamp, therefore, the illumination variation images each of which is generated under a single point source of light are enough. For the generation of the illumination variation images, the three-dimensional shape data and the surface reflectance data which have been stored are used. The illumination variation images can be generated by use of basic functions of computer graphics, for example. The details of the computer graphics functions have been described in a document: Mason Woo, Jackie Neider, and Tom Davis "Open GL programming Guide", Addison-Wesley Publishers Japan. In a standard function provided to computers, the reflectance property of the surface of the object is generally assumed to be perfect scattering and only shade is generated. However, in the present invention, a reflectance model that is close to actual surface reflectance property of the object is selected and used. The mirror reflection is taken into consideration and cast shadows are also reproduced by means of ray tracing, in order to generate images that are close to reality.

The above illumination variation image generation method by use of the CG functions of a computer is only an example. It is of course possible to generate each illumination variation image by calculating intensity of pixels that will be used for the comparison, by means of numerical calculations.

Hereafter, each image will be expressed by use of a column vector. Each component of the column vector indicates an intensity value of each

pixel in an area of the image that will be used for the comparison. When the number of the illumination variation images is N, by expressing each illumination variation image by a vector $\vec{K}_i$ (i = 1, 2, ・・・, N), a covariance matrix V can be expressed by the following [Equation 3].

[Equation 3]

$$S = \left[\vec{K}_1 \vec{K}_2 \cdots \vec{K}_N \right]$$

$$V = \frac{1}{N} SS^T$$

Eigenvalues σ_i and eigenvectors $\vec{B}_i$ (i = 1, 2, ・・・ M) of V are successively obtained for M largest eigenvalues starting from the largest eigenvalue, and the illumination variation space of an object "j" is approximated by an M-dimensional linear space Ψj whose bases are the eigenvectors $\{ \vec{B}_i \}$. The dimension number M of the illumination variation space may be determined in consideration of precision that is required of the illumination correction process. In the case where M eigenvectors are used, "cumulative contribution" of the M eigenvalues can be calculated by [Equation 4] as follows:

[Equation 4]

$$\frac{\sum_{i=1}^{M} \sigma_i}{\sum_{i=1}^{N} \sigma_i} \times 100[\%]$$

The cumulative contribution is an index indicating how precisely the illumination variation space can express the illumination variation images, when error between images is evaluated by use of the differences

of intensity values therebetween. By setting a threshold value for this index, the dimension number M can be determined automatically by finding a number M necessary for surpassing the threshold value.

Comparison processing of an object may be performed by use of the distance of illumination variation space between an input image vector $\vec{I}_q$ and a comparison target object as a measure. This distance exists in the illumination variation space Ψj, and is calculable as the distance between the input image and an image vector $\vec{I}_c$ being closest to the input image. While various measures can be used as a measure of a distance, a description will be given of an example in which a square error of intensity value is directly used, here.

In the case where this distant measure is used, the image vector $\vec{I}_c$ being closest to the vector $\vec{I}_q$ in the space Ψj can be generated by the following [Equation 5].

[Equation 5]

$$\vec{I}_c = \sum_{i=1}^{n} \left(\vec{I}_q \cdot \vec{B}_i \right) \vec{B}_i$$

A distance D (a sum of square of intensity value) between a reference image vector $\vec{I}_c$ and the input image vector $\vec{I}_q$ can be calculated by the following [Equation 6].

[Equation 6]

$$D = \left| \vec{I}_q - \vec{I}_c \right|^2$$

The value D is an evaluation value of similarity between the input image and the registered data, and based on this evaluation value, judgment processes such as whether or not the target image is the registered image, to which registered images the input image corresponds, to which registered image the input image is similar, are performed. For example, for simply judging whether or not the target image is the registered image, a threshold value D' is predetermined, and the target object is judged to be the registered object if $D < D'$.

Practical Example of the Invention

Fig. 1 is a block diagram showing the composition and procedure of an image comparison device in accordance with a first embodiment of the present invention. Fig. 2 is a composition diagram of this embodiment. This embodiment corresponds to the invention of claim 25.

As shown in Fig. 1, a registration means measures the three-dimensional shape of each object and the reflectance or color on the surface of the object by use of a three-dimensional shape measurement device, and stores both of the data. A comparison means photographs a two-dimensional image by use of a video camera, etc., and downloads the image into a processor which performs a comparison process, and performs a comparison process.

First, a registration means 100 registers three-dimensional shape and surface reflectance of an object as registered data to be used for comparison of objects.

A three-dimensional shape measurement means 110 measures the

three-dimensional shape of each object. For example, a three-dimensional shape measurement device which has been disclosed in Japanese Patent Application No.HEI11-123687 can be employed. Other three-dimensional shape measurement devices can be employed.

A reflectance measurement means 120 measures the reflectance of the surface of the object corresponding to the three-dimensional shape. For, example, if the three-dimensional shape measurement device disclosed in Japanese Patent Application No.HEI11-123687 is employed, color information on the surface of the object can be measured simultaneously with the three-dimensional shape. Hereinafter, the color information is substituted for the reflectance data.

A data storage means 130 stores the three-dimensional shape data and the reflectance data of each registered object. The data stored in the data storage means 130 are read out at a proper timing for the comparison process by a comparison means 200.

An object comparison process with images is performed in the comparison means 200 with respect to the object processed by the registration means 100.

In the comparison means 200, an input image being a comparison target is photographed by use of a photographing method such as a camera, and the obtained image is captured by a processor being a comparison means.

A photographing means 210 photographs the input image being the comparison target by means of a photographing means such as camera and video camera.

In a position/pose estimation means 220, parameters concerning position/pose or a photographing device being photographing condition when the input image is obtained. For example, the position/pose parameters include the translation distance (Tx, Ty, Tz) of the object, rotation angles (Rx, Ry, Rz), the focal length "f" of the camera, and the viewing angle "α". The position/pose estimation means 220 is provided with an interactive interface by which the user adjusts the position/pose parameters manually watching a display. For example, an image of a comparison target object generated by computer graphics by use of the above 8 position/pose parameters and the input image are displayed by being superimposed on the screen. The user successively adjusts the parameters so that the two images will be in register and thereby appropriate parameters are determined. The interactive interface is only an example and various types of devices can be employed. It is also possible that position/pose parameters are automatically calculated.

The illumination correction means 230 generates, by use of the above parameters determined by the position/pose estimation means 220, an image, as a reference image, which is in the same position/pose as that of the input image and is under an illumination condition that is the most similar to that of the input image. Fig.3 is a block diagram showing the detailed composition and process flow of the illumination correction means 230.

An illumination condition variation means 231 sets a sufficient number of illumination conditions capable of approximating the illumination variation space of the object. For example, considering one light source at an infinite-point, and the direction of a point source of light is expressed by angles (θ, ϕ) which indicate a longitude θ and a

latitude ϕ of a spherical surface of an object such as shown in Fig. 4. Each angle (θ, ϕ) is changed from -90° to 90° at intervals of 10°, and thereby, 361 types of illumination conditions are set. The type of light source, the interval or the range of illumination directions is only an example, and other settings can of course be employed.

An image generation means 232 reads the three-dimensional shape data and the reflectance data of the object j being a comparison target from the data storage means 130, and generates the illumination variation images by use of the position/pose parameters supplied from the position/pose estimation means 220 and the illumination conditions supplied from the illumination condition variation means 231 by use of CG functions. The above process can be implemented by use of basic functions of a computer being provided with graphics functions, for example. In the image generation by use of computer graphics, various types of surface reflectance models and camera models can be employed. For example, the pinhole camera model may be employed as the camera model and the perfect scattering model can be employed as the surface reflectance model. It is also possible to give shadows to the surface of the object by means of ray tracing, or to give specularity to the surface of the object by use of other reflectance models. In the image comparison process, reflectance property model, a light source model and a camera model are made to be close to reality, comparison quality can be improved. The image generation process can also be conducted by numerical calculations without using computer graphics.

The illumination variation space generation means 233 calculates illumination variation space from the illumination variation images by following the [Equation 3], and outputs the obtained basis vectors as the illumination variation space (basis vectors) Ψj. In this embodiment, M

basis vectors corresponding to the M largest eigenvalues are obtained starting from the largest eigenvalue, and the obtained M basis vectors are outputted as the illumination variation space Ψj. In order to determine the number of the basis vectors M, for example, as the number which surpass 95% of the cumulative contribution being calculated by the [Equation 4], in the case where the number of pixels equals to or less than *361* being the number of the illumination variation images, the number of pixels is N and N eigenvalues are obtained, and a number M that satisfies the $\frac{\sum_{i=1}^{M}\sigma_i}{\sum_{i=1}^{361}\sigma_i} \geq 0.95$ is obtained. M can be determined by applying various criterions.

An illumination condition estimation means 234 generates, as a reference image, which is the nearest to the input image and is in the illumination variation space Ψj according to the [Equation 5].

An image comparison means 240 calculates an evaluation value concerning the similarity between the input image and the generated reference image. Various calculation methods can be employed for the evaluation. For example, the sum of squares of difference of intensity value of each pixel of an image which is shown in the following [Equation 6] can be used as the evaluation value. A technique elaborated on in a document: Shigeru Akamatsu "Computer Recognition of Human Faces - A Survey -", The Transactions of the Institute of Electronics, Information and Communication Engineers D-II, Vol.J-80-D-II, No.8, pp.2131-2146 (1997), can also employed.

A comparison judgment means 250 judges whether or not the comparison target image is the registered image by processing the calculated evaluation value as a threshold value. When a plurality of

objects have been registered, the process from 230 to 240 are repeated for a plural times. In this case, the judgment means 250 can judge which registered object is the most similar to the target object. It is also possible to search for one or more registered objects having more than certain evaluation values as objects similar to the target object.

Next, a detailed description will be given of a second embodiment of the present invention with reference to Figs. 6 and 7. This embodiment corresponds to the invention claimed in claim 26.

Fig. 6 is a block diagram showing the composition and operation of an image comparison device in accordance with the second embodiment of the present invention. This embodiment differs from the first embodiment in that by photographing images under a plurality of illumination conditions, and by use of the images instead of the reflectance, illumination variations images are generated, instead of measuring the reflectance by use of the reflectance measurement means 120 in the first embodiment. Further, in the second embodiment, the illumination condition variation means 231 is not provided.

In a registration means 2100, as registration data to be used for comparison of the object, the three-dimensional shape of each object and image data of each object obtained under a plurality of illumination conditions are registered.

The three-dimensional shape measurement means 2110 measures the three-dimensional shape of each object by use of a three-dimensional shape measurement device such as the device disclosed in Japanese Patent Application No.HEI11-123687.

The texture image photographing means 2120 actually sets illumination conditions which are equivalent to those set and outputted by the illumination condition variation means of the first embodiment, and photographs each object under the illumination conditions, and outputs them as texture images. For example, a hemispherical scaffold is set up in front of the registered object and an appropriate number of illumination lamps are fixed to the scaffold. Concretely, in the angles (θ, ϕ) shown in Fig. 4 with respect to the object, the lamps are fixed to points corresponding to angles from $-90°$ to $90°$ at intervals of $15°$ for example, and the object is photographed repeatedly by successively turning each lamp on. It is also possible to photograph the registered object repeatedly moving a lamp by a manipulator and turning the lamp on repeatedly. The images obtained as above are outputted as texture images.

A data storage means 2130 stores the three-dimensional shape data of the objects and the texture images. The registered data are read out at the time of the comparison process by the comparison means.

In a following comparison means 2200, an object comparison process with images are performed with respect to the object processed by the above comparison means 2100.

A photographing means 2210 and a position/pose estimation means 2220 are each performs the same processes as the photographing means 210 and the position/pose estimation means 220 in the first embodiment.

The illumination correction means 2200 does not include the illumination condition variation means 231, and therefore, in an image generation means 2232, illumination variation images are generated by

use of, as intensity value of a surface of the object, the texture images being photographed by the texture image photographing means 2120. Fig. 7 is a block diagram showing the process flow of an illumination correction means according to the second embodiment.

The image generation means 2232 reads out the three-dimensional shape data and the texture images of a comparison target object "*j*" from the data storage means 2130, and generates illumination variation images by computer graphics, by use of the position/pose obtained by the position/pose estimation means 2220 and each of the texture images. The process can be conducted by means of texture mapping, which is a basic function of a computer having graphic functions. In the second embodiment, various types of camera models such as the pinhole camera model can be employed. The texture images employed in the second embodiment are actually photographed images, and therefore, there is no need to generate shadows and specularity by computer graphics as in the first embodiment.

An illumination variation space generation means 2233 and below performs the same processes as those of the first embodiment.

In the following, a detailed description will be given of a third embodiment of the present invention. This embodiment corresponds to the invention claimed in claim 27.

Fig. 8 is a block diagram in accordance with the third embodiment of the present invention. In this embodiment, instead of the three-dimensional shape measurement means 3110 which measures the three-dimensional shapes of all objects when registering a plurality of objects in the first embodiment, by measuring the three-dimensional

shapes of one or a small number of objects, an average shape generation means 3150 generates an average three-dimensional shape of the measured objects. The third embodiment is different from the first embodiment in that shapes of all the comparison target objects are not measured, and that a comparison means 3200 uses the three-dimensional shape of the average shape.

First, in the three-dimensional shape measurement means 3110, as registered data used for comparison of objects, three-dimensional shape and image data under various illumination conditions with respect to objects 1 and 2 are registered.

The three-dimensional shape measurement means 3110 measures three-dimensional shapes of the objects 1 and 2, by use of such a three-dimensional shape measurement device as disclosed in Japanese Patent Application No.HEI11-123687.

The average shape generation means 3150 translates the three-dimensional shape data of the registered object 1 or 2 so that the barycenters of the objects 1 and 2 will overlap one another as shown in a left drawing of Fig. 9, sets sections that are perpendicular to the z-axis at appropriate intervals, and calculates average shapes on each of the sections. As shown in a right drawing in Fig. 9, a line being average calculation line is drawn outward from the barycenter of the object on the section, and intersection points P_1 and P_2 of the average calculation line with shapes of the objects 1 and 2 are obtained. The three-dimensional coordinates of a point P_m of the average shape are obtained by averaging three-dimensional coordinates (x_1, y_1, z_1) and (x_2, y_2, z_2) of the surface points P_1 and P_2 as expressed by

$\left(\frac{x_1+x_2}{2},\frac{y_1+y_2}{2},\frac{z_1+z_2}{2}\right)$. By performing the above process by repeating the above calculation around the barycenter at proper intervals, the average shape of the objects 1 and 2 can be generated. Thereby, in the average shape measurement means 3150, the generated average shape can be outputted.

The reflectance measurement means 3120 measures the reflectance of the surface of each object 1 and 2 corresponding to the three-dimensional shape. If the three-dimensional shape measurement device of Japanese Patent Application No.HEI11-123687 is employed, color information on the surface of the object can be measured simultaneously with the three-dimensional shape. In the following, the color information is substituted for the reflectance data. The correspondence between each point of the average three-dimensional shape and the color information of each registered object can be set as follows. That is, if we express the three-dimensional shape data of the objects 1 and 2 which have been used for the calculation of the three-dimensional coordinates of the average three-dimensional shape P_m as P_1 and P_2, reflectance data of the object 1 corresponding to the P_m is the reflectance corresponding to the P_1, and in the same way, reflectance data of the object 2 corresponding to the average shape P_m is the reflectance corresponding to P_2.

The data storage means 3130 stores the average shape inputted from the three-dimensional shape measurement means 3110 and the reflectance of the objects 1 and 2 inputted from the reflectance measurement means 3120.

The processing of the comparison means 3200 is basically the same

as that of the first embodiment, except that the average three-dimensional shape data read out from the data storage means 3130 is changed to the average shape of each of objects 1 and 2.

While an embodiment in which an average shape of two objects is stored when two objects are registered has been explained above, this embodiment is only for an example. An embodiment in which the number of objects is more than three and arbitrary number thereof are calculated for obtaining the average shape is also possible by the same processing.

In the following, a detailed description will be given of a fourth embodiment of the present invention. This embodiment corresponds to the invention claimed in claim 30. In the fourth embodiment, human face is used as an example of a comparison target object.

Fig. 10 is a block diagram showing the composition and process flow of an image comparison device in accordance with this embodiment. Differently from the image comparison device of the first embodiment, a registration means 4100 is further provided with a feature point extraction means 4140 which extracts feature points where intensity etc. changes steeply from each object and outputs the extracted points as the feature point positions. A data storage means 4130 of the fourth embodiment also stores the feature point positions. In a comparison means 4200 of the fourth embodiment, a position/pose estimation means 4220 reads out the feature point positions from the data storage means 4130 and automatically executes the position/pose estimation.

First, in the registration means 4100, the three-dimensional shape and reflectance of each object are measured as the registered data to be

used for the object comparison, and three-dimensional coordinates of feature points of the object are obtained by use of the measured three-dimensional shape and reflectance. The three-dimensional shape, the reflectance or color information and the feature point positions are registered.

The three-dimensional shape measurement means 4110, which is provided with a three-dimensional shape measurement device, measures the three-dimensional shape of each object. While the three-dimensional shape measurement device of Japanese Patent Application No.HEI11-123687 is employed in the fourth embodiment as an example, other devices can of course be used.

The reflectance measurement means 4120 measures the reflectance of the surface of the object corresponding to the three-dimensional shape. If the three-dimensional shape measurement device of Japanese Patent Application No.HEI11-123687 is employed, color information on the surface of the object can be measured simultaneously with the three-dimensional shape. The color information obtained by the device will hereafter be substituted for the reflectance.

The feature point extraction means 4140 detects points or areas where intensity etc. changes steeply (hereinafter referred to as feature points) of the object on an image, and outputs the three-dimensional coordinates of the feature points (feature point positions) in the data storage means 4130. For example, when human faces are comparison target objects, parts where reflectance changes steeply such as tails of eyes, lips, etc., parts where the three-dimensional shape changes steeply such as tip of nose etc., are detected. The feature point detection process can be conducted by manual operation. For the automatic

feature point extraction process, various methods including those disclosed in the aforementioned Japanese Patent No.2872776: "face image comparison device" and the aforementioned Japanese Patent Application Laid-Open No.HEI6-168317: "personal identification device" can be employed. In this embodiment, twelve points (0 ~ 11) shown in Fig.12 are used as the feature points. The definition of the feature points can of course be altered depending on what the comparison target object is. In the following explanation, the feature point positions being three-dimensional coordinates will be expressed by use of vectors $\vec{A_i} = (x_i, y_i, z_i)$ $(i = 0, 1, \cdot \cdot \cdot, 11)$.

The data storage means 4130 stores the three-dimensional shapes, the reflectance and the feature point positions of the registered objects. The registered data is read out when the comparison step is conducted.

In the following comparison means 4200, an object comparison process is performed with respect to the object processed by the registration means 4100.

The photographing means 4210, which is provided with a camera, a video camera, etc., photographs the comparison target object and thereby obtains the input image.

The position/pose estimation means 4220 estimates the parameters concerning the position/pose of the object and parameters concerning the photographing device being the condition at the time when the target object was photographed. Fig. 11 is a block diagram showing the composition and process flow of the position/pose estimation means 4220.

The input image feature point extraction means 4221 extracts, from the input image, feature points being the same position as feature point vectors $\vec{A}_i$ extracted by the feature point extraction means 4140 of the registration means 4100, and outputs position vectors on the image $\vec{B}_i = (u_i, v_i)$ ($i = 0, 1, \cdots, 11$) to the position/pose calculation means 4222 as input image feature point positions. The input image feature point extraction process can be conducted by manual operation of an operator seeing the input image on the screen. The methods employed by the feature point extraction means 4140 such as the methods disclosed in the aforementioned Japanese Patent Application Laid-Open No.HEI6-168317: "personal identification device" can be used. While human face comparison is taken as an example in this embodiment, the image comparison device of the fourth embodiment can be used for the comparison of polyhedron-like objects, for example, by using apexes of the objects as the feature points. Edges are extracted from each object in the image, and the apexes of the object are detected as intersection points of the edges. When some characteristic patterns exist on the surfaces of the objects, the positions of the patterns can be used.

The position/pose calculation means 4222 calculates parameters concerning the position/pose of the target object in the input image and parameters concerning the photographing device by use of the feature point positions read out from the data storage means 4130 and the input image feature point positions, and outputs the calculated parameters as the position/pose. While various method such method as of Document 15 can be employed, in this embodiment, the position/pose parameters employed in this embodiment include, for example, the translation distance (Tx, Ty, Tz) of the object, rotation angles (Rx, Ry, Rz) of the

object around the *x*-axis, *y*-axis and *z*-axis and the focal length "*f*" of the camera. The pinhole camera model is employed as the camera model. The relationship between the feature point position vector $\vec{A_i}$ and the input image feature point position vector $\vec{B_i}$ can be expressed by the following [Equation 7].

[Equation 7]

$$\begin{bmatrix} u_i \\ v_i \end{bmatrix} = \frac{f}{c} \begin{bmatrix} a \\ b \end{bmatrix}$$

where "*a*", "*b*" and "*c*" are defined as following [Equation 8]:

[Equation 8]

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = R \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix}$$

where "*R*" is the following rotation matrix expressed by the [Equation 9]:

[Equation 9]

$$R = \begin{bmatrix} \cos R_y \cos R_z & -\cos R_x \sin R_z + \sin R_x \sin R_y \cos R_z & \sin R_z \sin R_x + \cos R_x \sin R_y \cos R_z \\ \cos R_y \sin R_z & \cos R_x \cos R_z + \sin R_x \sin R_y \sin R_z & -\sin R_x \cos R_z + \cos R_x \sin R_y \sin R_z \\ -\sin R_y & \sin R_x \cos R_y & \cos R_x \cos R_y \end{bmatrix}$$

The position/pose parameters *Rx, Ry, Rz, Tx, Ty, Tz, f* by optimization calculation so that the sum of the differences between the value obtained by the [Equation 7] and the input image feature point positions with respect to the 12 feature points will be the smallest. The optimization calculation can be executed in various ways. The obtained *Rx, Ry, Rz, Tx, Ty, Tz, f* are outputted as position/pose parameters. The definitions of the position/pose parameters and the camera model and the calculation method explained above are only examples, and thus, the position/pose calculation process can be conducted according to various methods.

Processes of the illumination correction means 4230 and below are same as those of the first embodiment.

In the following, a detailed description will be given of an image comparison device in accordance with a fifth embodiment of the present invention. This embodiment corresponds to the invention claimed in claim 28 and 29.

In this embodiment, the objects to be registered are industry products etc. whose design drawings of the shapes have been saved as CAD data and whose surface painting specifications etc. have been designated and written in drawings. Differently from the first embodiment, a three-dimensional shape measurement means 110 of the fifth embodiment obtains the three-dimensional shape data from the CAD data of design drawings, and a reflectance measurement means 120 of the fifth embodiment obtains the reflectance data by reading drawings.

The three-dimensional shape measurement means 110 reads the CAD data of the of the design drawings, converts the CAD data into a data format that can be handled by the comparison means 200, and outputs the converted data. The reflectance measurement means 120 reads data concerning the colors, surface finishing conditions, etc. of parts of the objects from the design drawings, converts the data into reflectance data, and outputs the data. The data storage means 130 stores the outputted three-dimensional shape data and the reflectance data. The comparison means 200 of the fifth embodiment conducts the comparison step in the same way as the first embodiment.

As described in the above embodiment, the present invention can be applied to general objects. Especially, the present invention can be applied to the comparison of the type and form of automobiles, and also the comparison of human faces.

As set forth hereinabove, while a detailed description has been given of the embodiments of the present invention with reference to the drawings, it is not to be restricted by those embodiments, and change or modification of the embodiment is to be appreciated without departing from the subject matter of the present invention. The present invention can also be implemented by use of a computer program.

Effect of the Invention

According to the present invention, three-dimensional shapes of objects and reflectance of surface of the objects or images under appropriate conditions of illumination are measured only by the registration means, and photographing device such as video camera for photographing general two-dimensional images is enough as a photographing means in a comparison means, and thereby, a practical device can be constructed without a need of a three-dimensional shape measurement device. Also, three-dimensional shapes are registered, and therefore, perfect correction is possible with respect to the change of the three-dimensional position/pose in the input images. Further, perfect correction is possible with respect to the variation of illumination conditions. The present invention can be applied to the target objects whose surface reflectance properties are not perfect scattering, and also applied to the target objects which cast shadows due to light occlusion by other parts, specularity, etc. occurring on the surfaces. Thus, the present invention can be applied to comparison of general objects in wider range than the above methods (8) or (9). Moreover, illumination

variation images can automatically be generated by use of registered three-dimensional shapes and reflectance, and accordingly, the registration step can be performed easily since photographing a lot of images is not needed. Furthermore, by use of the cumulative contribution, an enough dimension number of subspace as an approximation of the illumination variation space can be obtained, and therefore, enough accuracy of the image comparison can be obtained.

Brief Description of the Drawings

[Fig. 1] is a block diagram showing the process flow of an image comparison device in accordance with a first embodiment of the present invention.

[Fig. 2] is a constitutive diagram of an image comparison device in accordance with the first embodiment of the present invention.

[Fig. 3] is a block diagram showing the process flow of an illumination correction process in accordance with the first embodiment.

[Fig. 4] is a diagram for explaining angles indicating the direction of illuminations which are used for the setting of illumination conditions with respect to an object.

[Fig. 5] is a diagram showing an example of an object comparison device using images.

[Fig. 6] is a block diagram showing the process flow of an image comparison device in accordance with a second embodiment of the present invention.

[Fig. 7] is a block diagram showing the process flow of an illumination correction process in accordance with the second embodiment of the present invention.

[Fig. 8] is a block diagram showing the process flow in accordance with a third embodiment of the present invention.

[Fig. 9] is diagrams for explaining a generation method of an average shape.

[Fig. 10] is a block diagram showing the process flow in accordance with a fourth embodiment of the present invention.

[Fig. 11] is a block diagram showing the process flow of a position/pose estimation process in accordance with the fourth embodiment of the present invention.

[Fig. 12] is a diagram showing an example of points employed as feature points of a target object.

[Fig. 13] is a diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which only two-dimensional images are employed in both the registration step and the comparison step.

[Fig. 14] is a diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which three-dimensional shapes are measured in both the registration step and the comparison step.

[Fig. 15] is a diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which two-dimensional images are employed in both the registration step and the comparison step, and standard three-dimension shape is employed in the position/pose correction step.

[Fig. 16] is a diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which images are photographed under a lot of position/pose conditions in the registration step and recognition is performed.

[Fig. 17] is a diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which two-dimensional images are photographed under a plurality of illumination conditions in the registration step, and illumination condition correction is performed.

[Fig. 18] is a diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which two-dimensional images are photographed under a plurality of illumination conditions in the registration step, and illumination condition correction is performed.

Title of Document

Abstract

Abstract

Problem

To provide an image comparison device, an image comparison method and a memory medium, where three-dimension shapes are not needed to be measured in a comparison step, and identification of whether or not a target object is a registered object, comparison of which registered object is the target object, and a search of similar objects are performed by use of images photographed with various position/pose of objects and under various illumination conditions.

Means of Solving

A registration means 100 measures the three-dimensional shape and surface reflectance of an object to be registered and stores them as registered data. In a comparison means 200 photographs an input image by a photographing means 210 such as camera. A position/pose estimation means 220 estimates the position/pose of the object in the input image by use of the registered three-dimension shape and reflectance. An illumination correction means 230 generates, as a reference image, an image of the object in the same position/pose as the object in the input image and under the same illumination condition as in the input image by use of the registered three-dimensional shape and reflectance. An image comparison means 240 calculates an evaluation value concerning the similarity between the reference image and the input image. A judgment means 250 performs comparison judgment based on the evaluation value.

Selected Drawing

[Fig. 1]

Drawings

FIG. 1

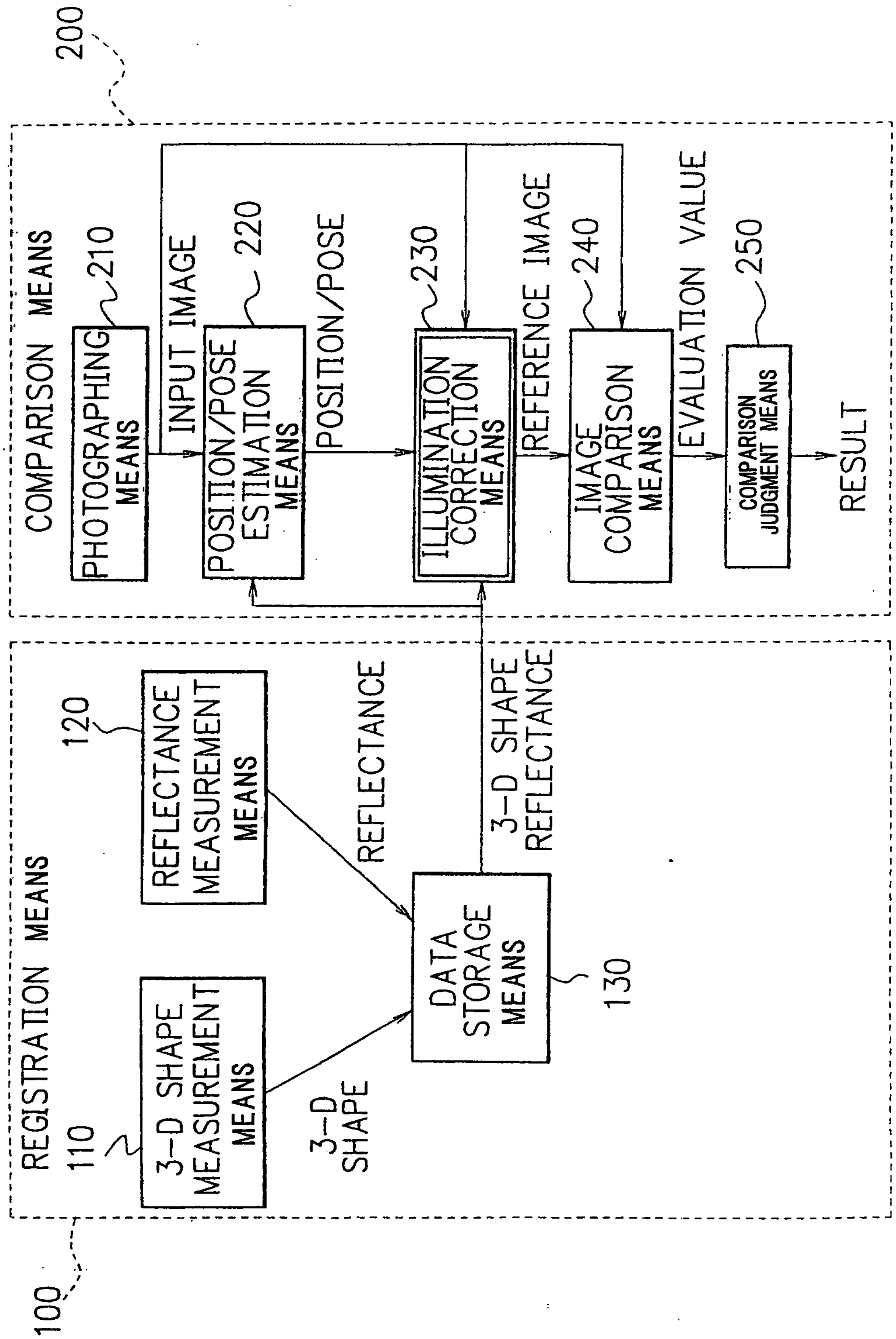
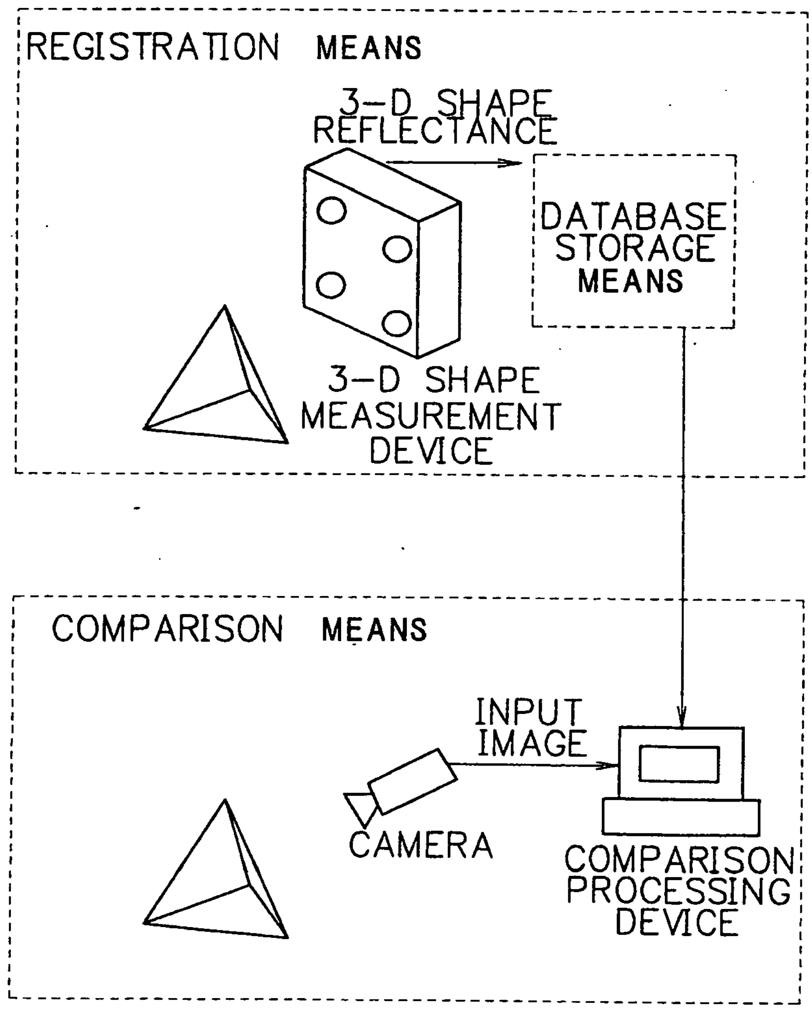


FIG. 2



REGISTRATION MEANS
3-D SHAPE
REFLECTANCE
DATABASE
STORAGE
MEANS
3-D SHAPE
MEASUREMENT
DEVICE
COMPARISON MEANS
INPUT
IMAGE
CAMERA
COMPARISON
PROCESSING
DEVICE

FIG. 3

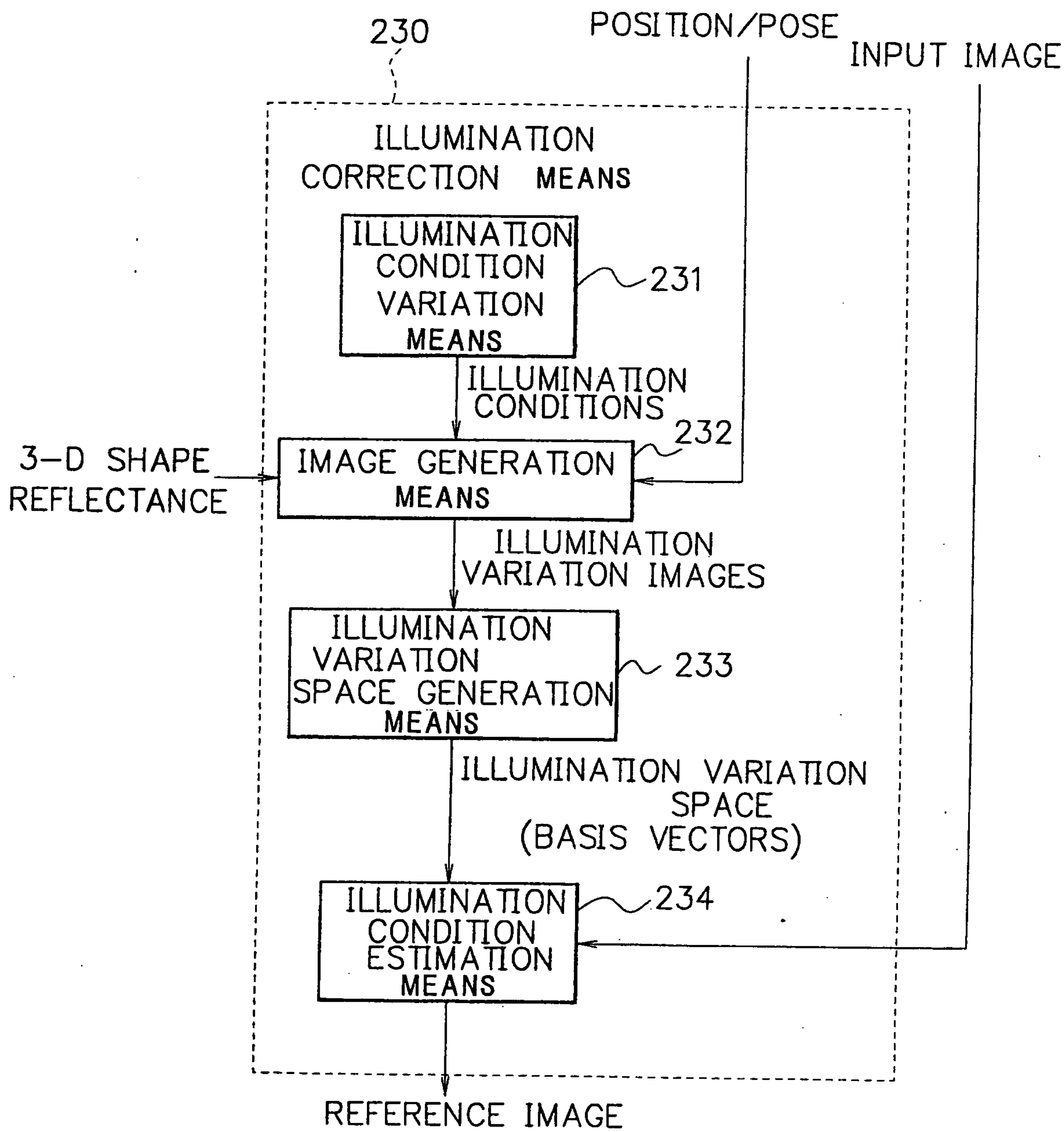

230
POSITION/POSE
INPUT IMAGE
ILLUMINATION CORRECTION MEANS
ILLUMINATION CONDITION VARIATION MEANS
231
ILLUMINATION CONDITIONS
232
3-D SHAPE REFLECTANCE
IMAGE GENERATION MEANS
ILLUMINATION VARIATION IMAGES
ILLUMINATION VARIATION SPACE GENERATION MEANS
233
ILLUMINATION VARIATION SPACE (BASIS VECTORS)
234
ILLUMINATION CONDITION ESTIMATION MEANS
REFERENCE IMAGE

FIG. 4

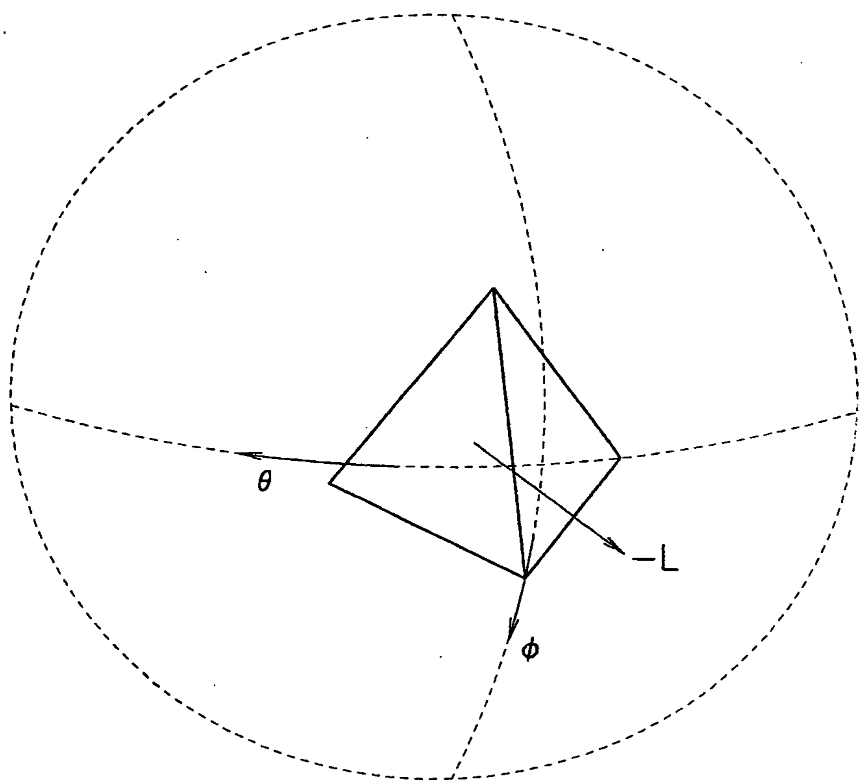
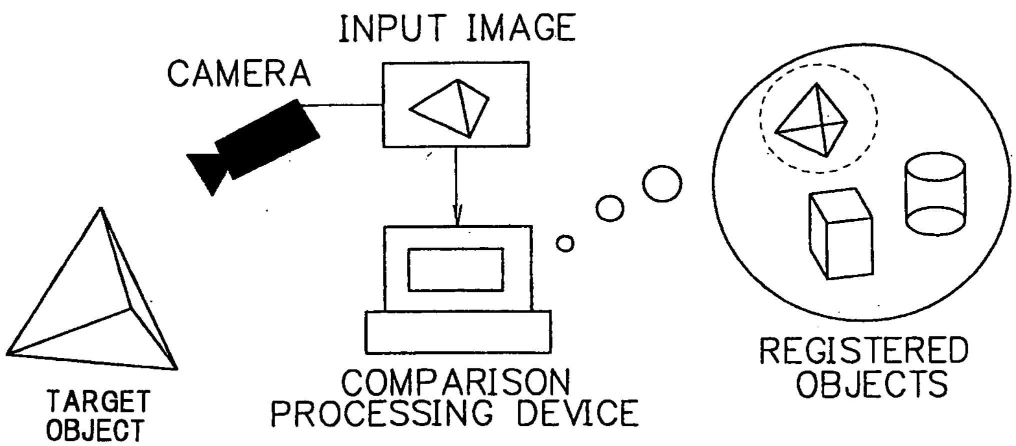
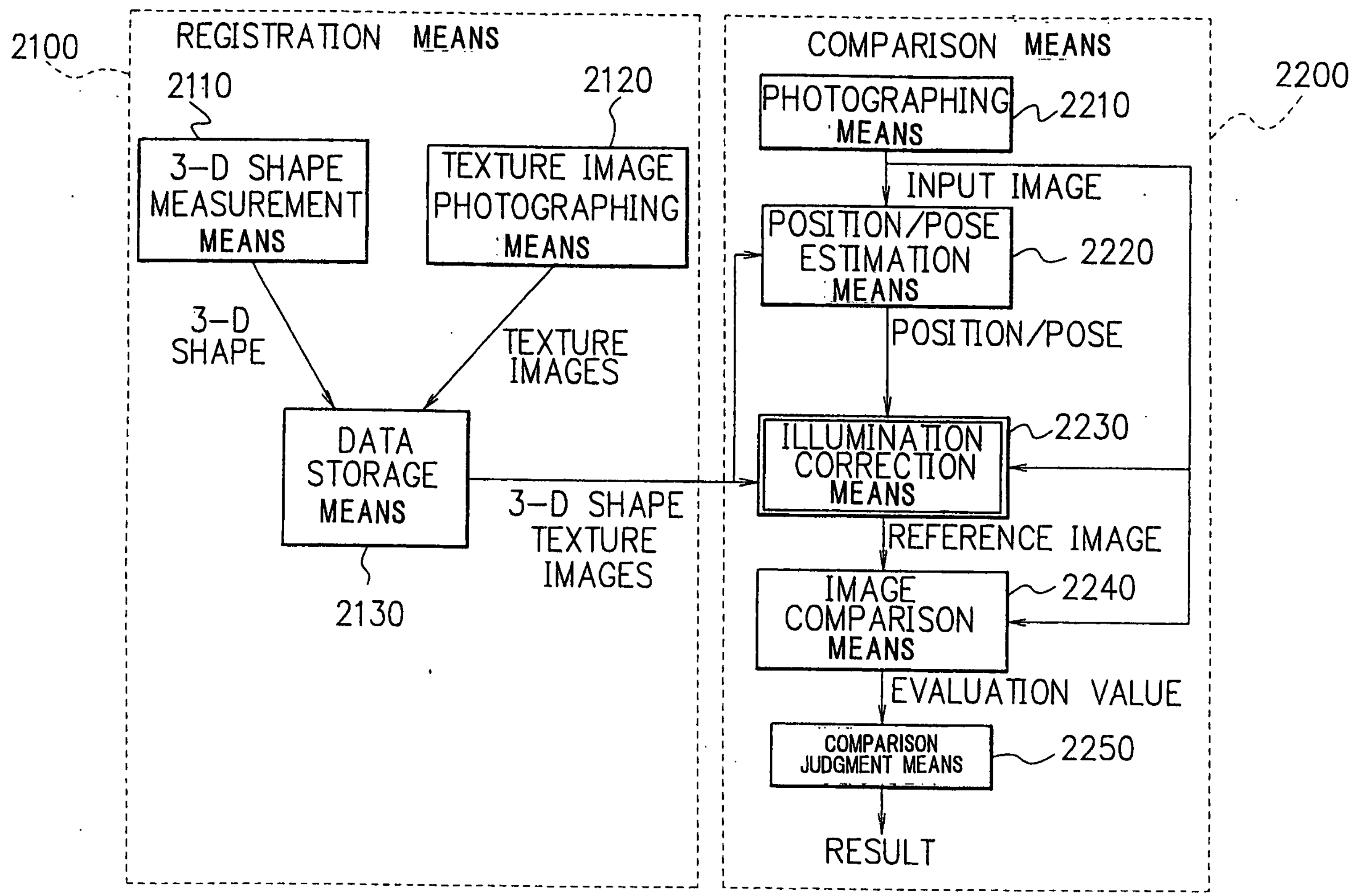


FIG. 5



INPUT IMAGE
CAMERA
TARGET OBJECT
COMPARISON PROCESSING DEVICE
REGISTERED OBJECTS

FIG. 6



2100
REGISTRATION MEANS
2110
3-D SHAPE MEASUREMENT MEANS
2120
TEXTURE IMAGE PHOTOGRAPHING MEANS
3-D SHAPE
TEXTURE IMAGES
DATA STORAGE MEANS
2130
3-D SHAPE TEXTURE IMAGES
COMPARISON MEANS
2200
PHOTOGRAPHING MEANS
2210
INPUT IMAGE
POSITION/POSE ESTIMATION MEANS
2220
POSITION/POSE
ILLUMINATION CORRECTION MEANS
2230
REFERENCE IMAGE
IMAGE COMPARISON MEANS
2240
EVALUATION VALUE
COMPARISON JUDGMENT MEANS
2250
RESULT

FIG. 7

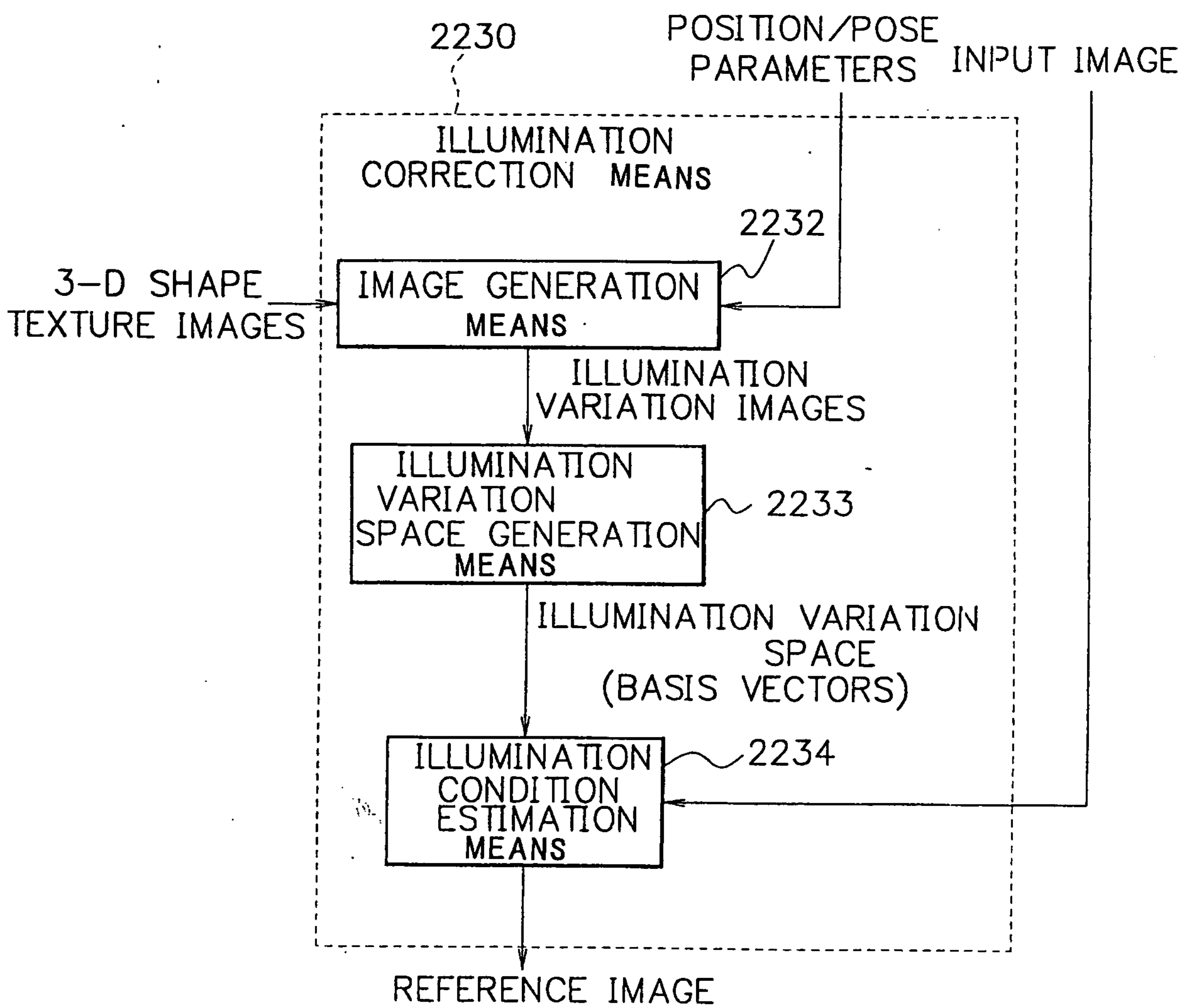

2230
POSITION/POSE PARAMETERS
INPUT IMAGE
ILLUMINATION CORRECTION MEANS
2232
3-D SHAPE
TEXTURE IMAGES
IMAGE GENERATION MEANS
ILLUMINATION VARIATION IMAGES
ILLUMINATION VARIATION SPACE GENERATION MEANS
2233
ILLUMINATION VARIATION SPACE
(BASIS VECTORS)
ILLUMINATION CONDITION ESTIMATION MEANS
2234
REFERENCE IMAGE

FIG. 8

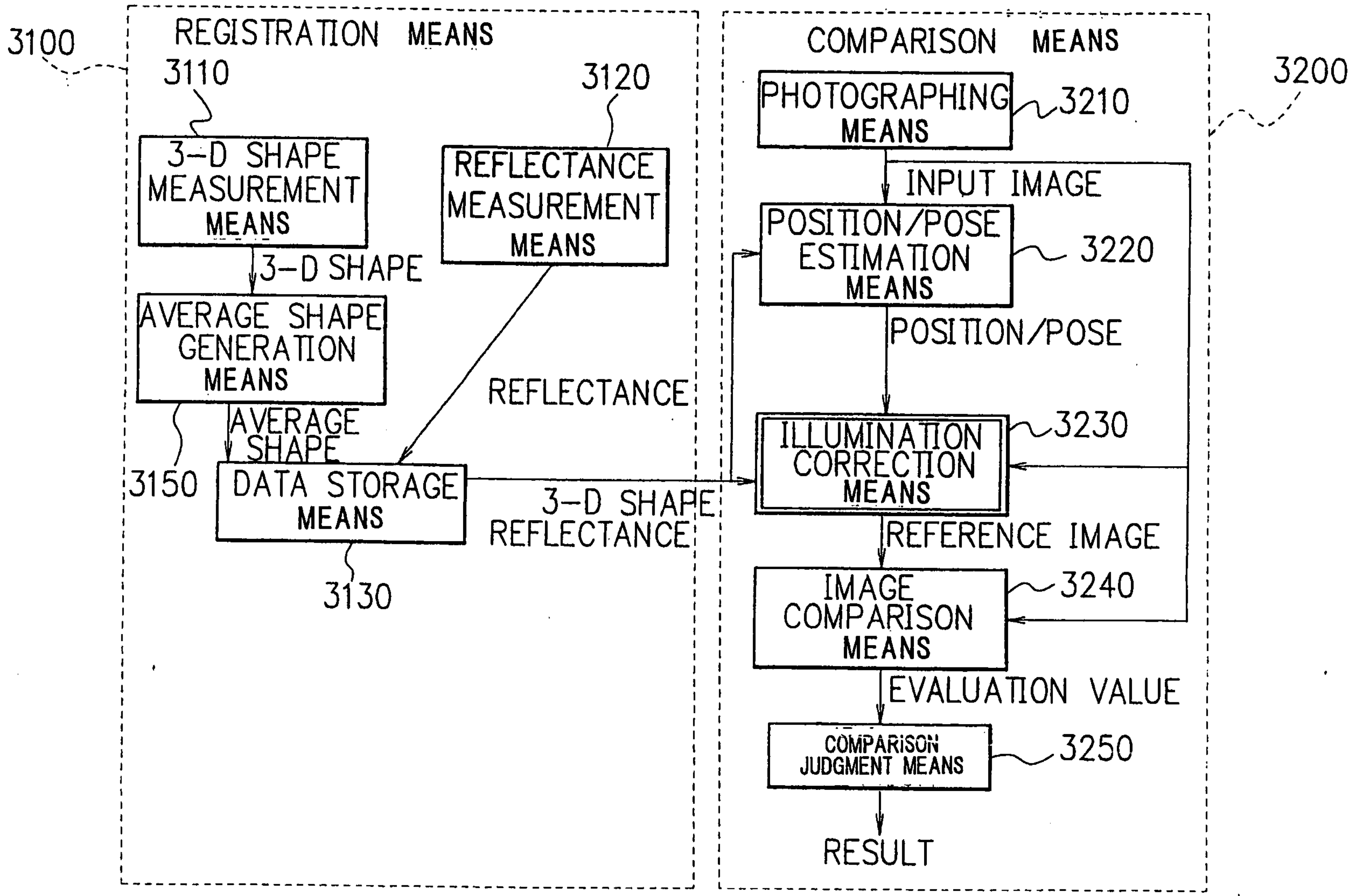

3100
REGISTRATION MEANS
3110
3-D SHAPE MEASUREMENT MEANS
3-D SHAPE
AVERAGE SHAPE GENERATION MEANS
3150
AVERAGE SHAPE
DATA STORAGE MEANS
3130
3120
REFLECTANCE MEASUREMENT MEANS
REFLECTANCE
3-D SHAPE
REFLECTANCE
3200
COMPARISON MEANS
PHOTOGRAPHING MEANS
3210
INPUT IMAGE
POSITION/POSE ESTIMATION MEANS
3220
POSITION/POSE
ILLUMINATION CORRECTION MEANS
3230
REFERENCE IMAGE
IMAGE COMPARISON MEANS
3240
EVALUATION VALUE
COMPARISON JUDGMENT MEANS
3250
RESULT

FIG. 9

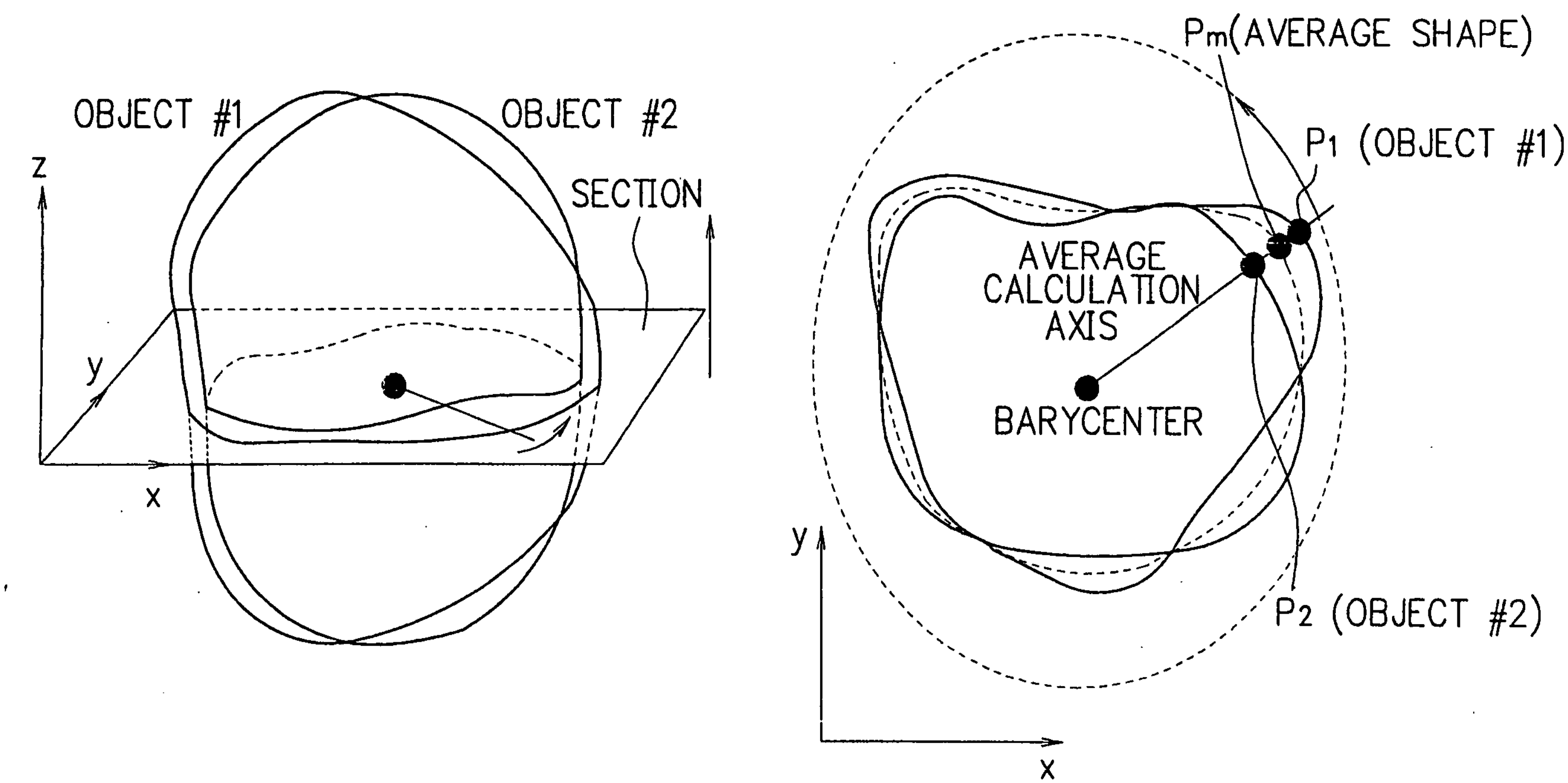

OBJECT #1
OBJECT #2
SECTION
z
y
x
P_m(AVERAGE SHAPE)
P_1 (OBJECT #1)
AVERAGE CALCULATION AXIS
BARYCENTER
P_2 (OBJECT #2)
y
x

FIG. 10

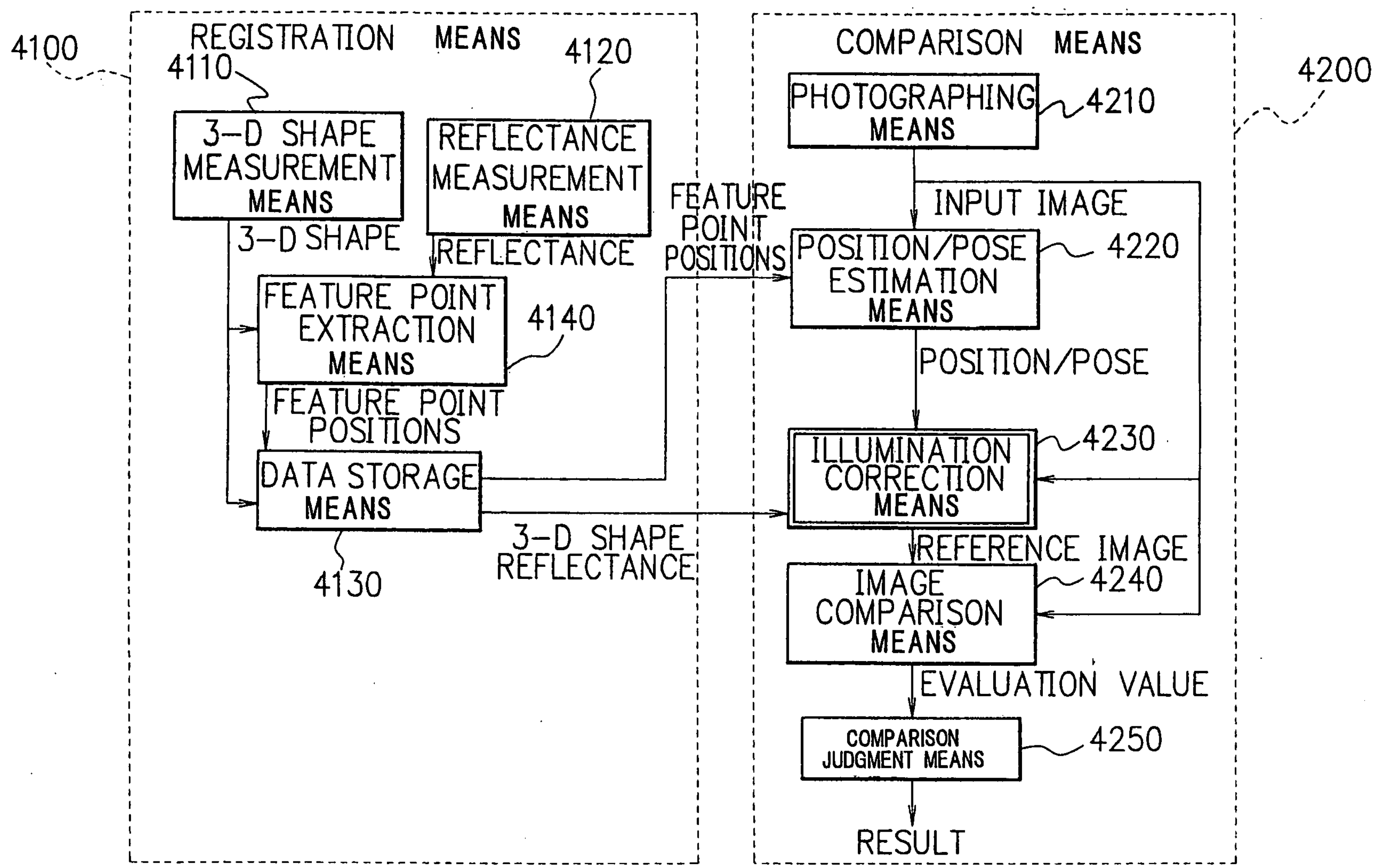
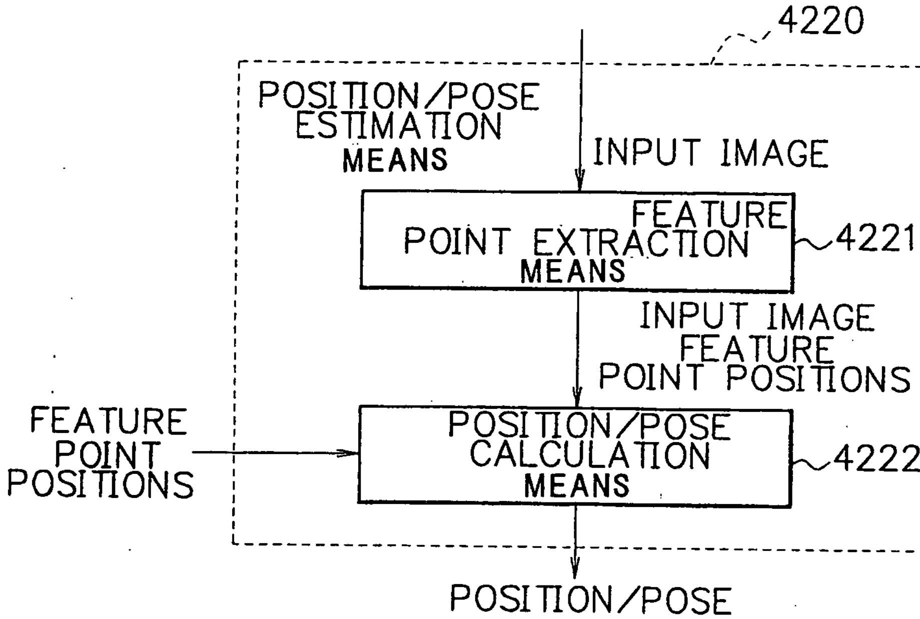
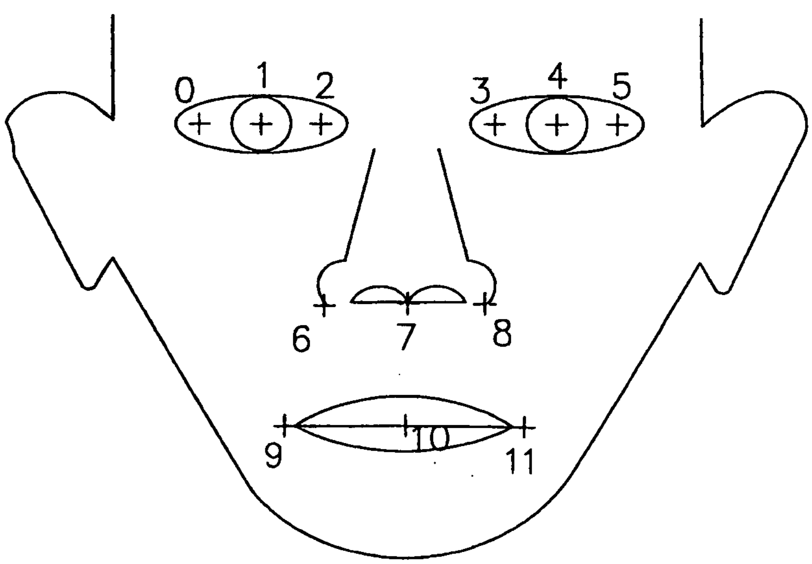

4100
REGISTRATION MEANS
4110
3-D SHAPE MEASUREMENT MEANS
4120
REFLECTANCE MEASUREMENT MEANS
3-D SHAPE
REFLECTANCE
FEATURE POINT EXTRACTION MEANS
4140
FEATURE POINT POSITIONS
DATA STORAGE MEANS
4130
3-D SHAPE REFLECTANCE
FEATURE POINT POSITIONS
COMPARISON MEANS
4200
PHOTOGRAPHING MEANS
4210
INPUT IMAGE
POSITION/POSE ESTIMATION MEANS
4220
POSITION/POSE
ILLUMINATION CORRECTION MEANS
4230
REFERENCE IMAGE
IMAGE COMPARISON MEANS
4240
EVALUATION VALUE
COMPARISON JUDGMENT MEANS
4250
RESULT

FIG. 11



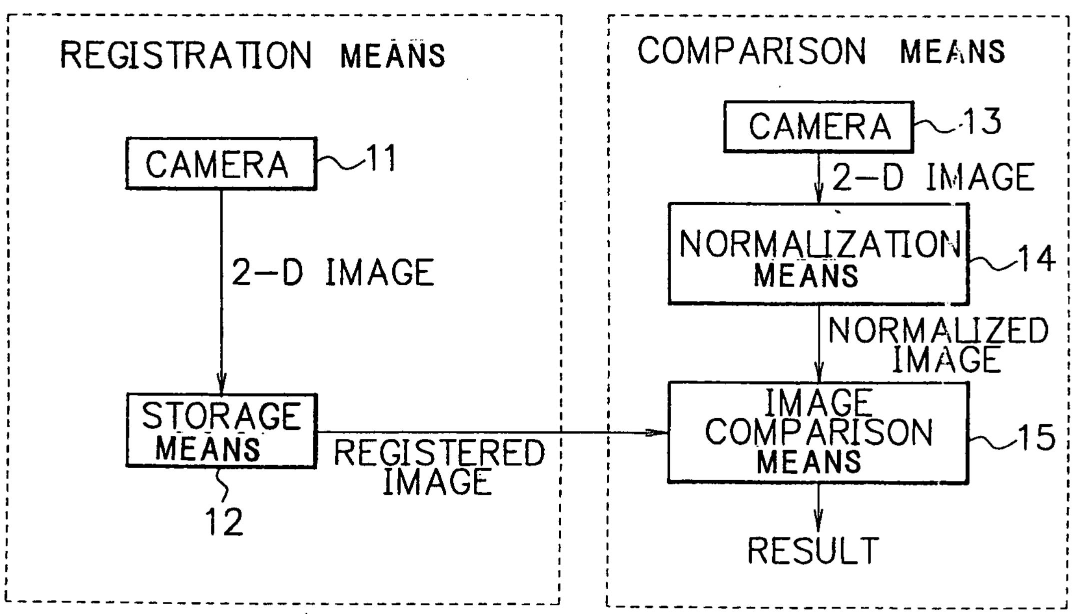
4220
POSITION/POSE ESTIMATION MEANS
INPUT IMAGE
FEATURE POINT EXTRACTION MEANS
4221
INPUT IMAGE FEATURE POINT POSITIONS
FEATURE POINT POSITIONS
POSITION/POSE CALCULATION MEANS
4222
POSITION/POSE

FIG. 12



0
1
2
3
4
5
6
7
8
9
10
11

FIG. 13



REGISTRATION MEANS
CAMERA
11
2-D IMAGE
STORAGE MEANS
12
REGISTERED IMAGE
COMPARISON MEANS
CAMERA
13
2-D IMAGE
NORMALIZATION MEANS
14
NORMALIZED IMAGE
IMAGE COMPARISON MEANS
15
RESULT

FIG. 14

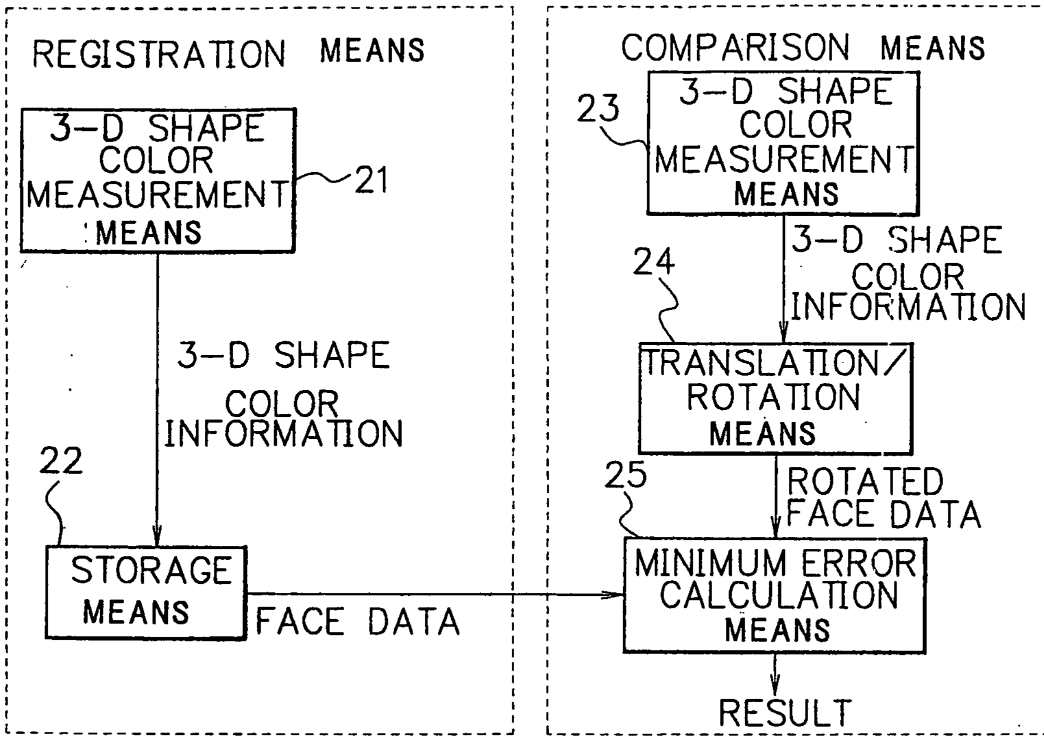

REGISTRATION MEANS
3-D SHAPE COLOR MEASUREMENT MEANS
21
3-D SHAPE COLOR INFORMATION
22
STORAGE MEANS
FACE DATA
COMPARISON MEANS
23
3-D SHAPE COLOR MEASUREMENT MEANS
3-D SHAPE COLOR INFORMATION
24
TRANSLATION/ ROTATION MEANS
25
ROTATED FACE DATA
MINIMUM ERROR CALCULATION MEANS
RESULT

FIG. 15

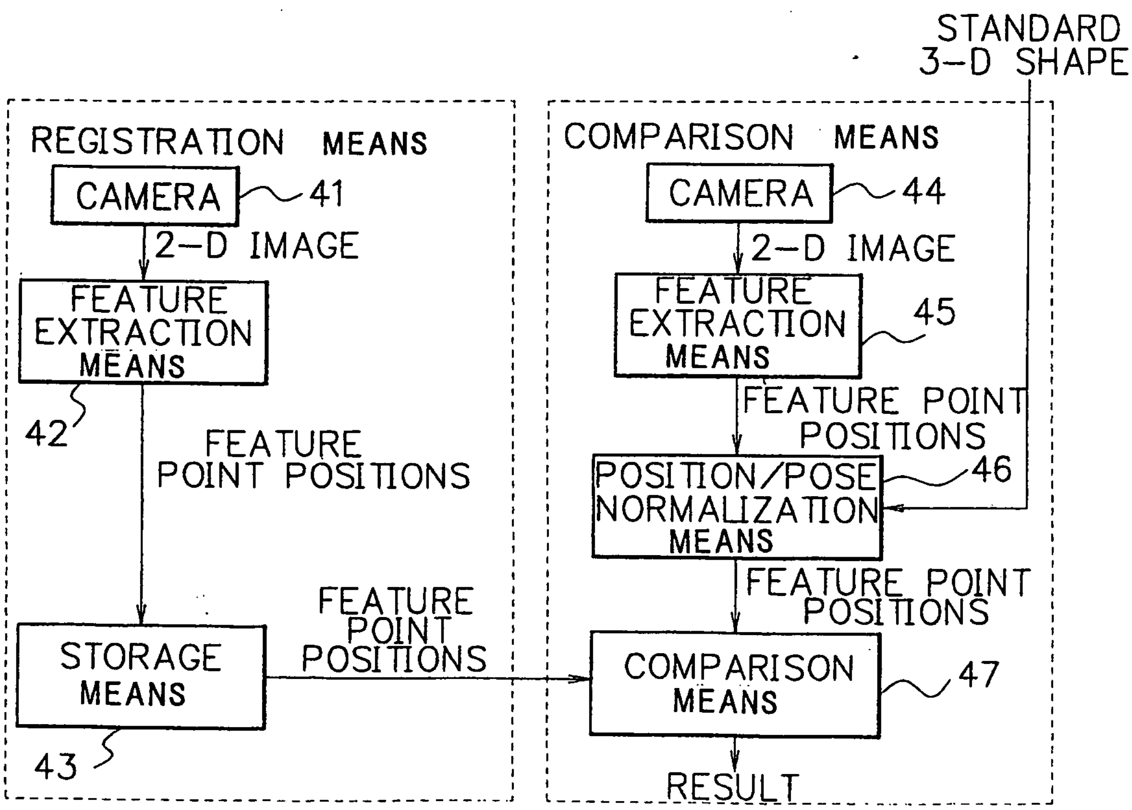
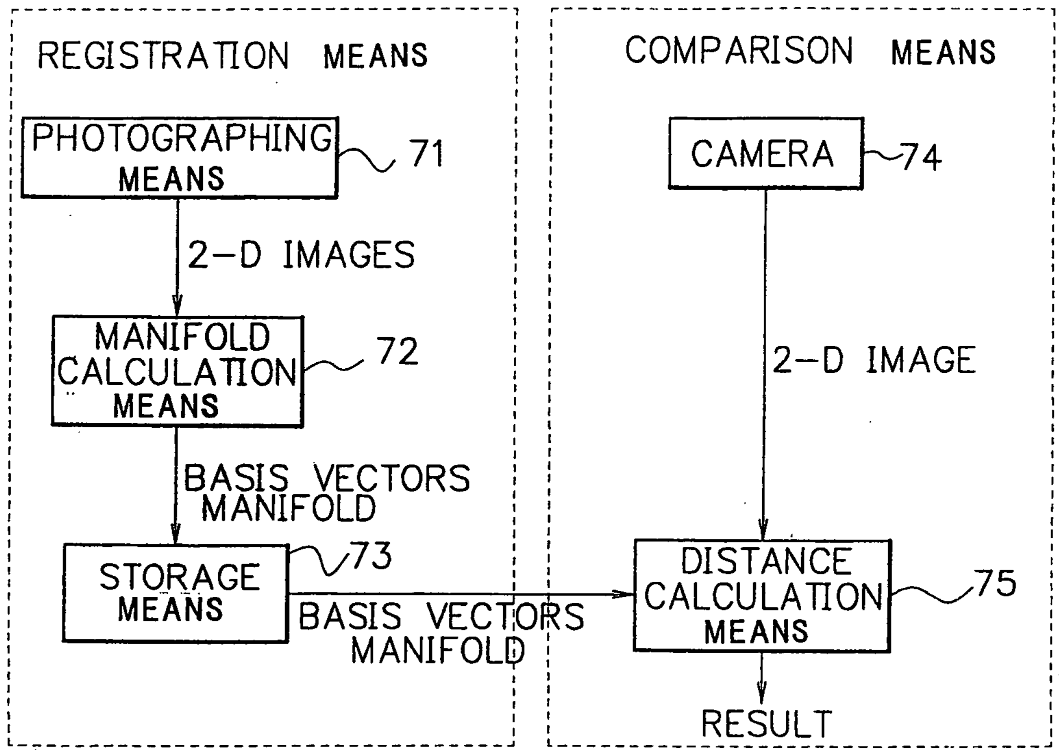
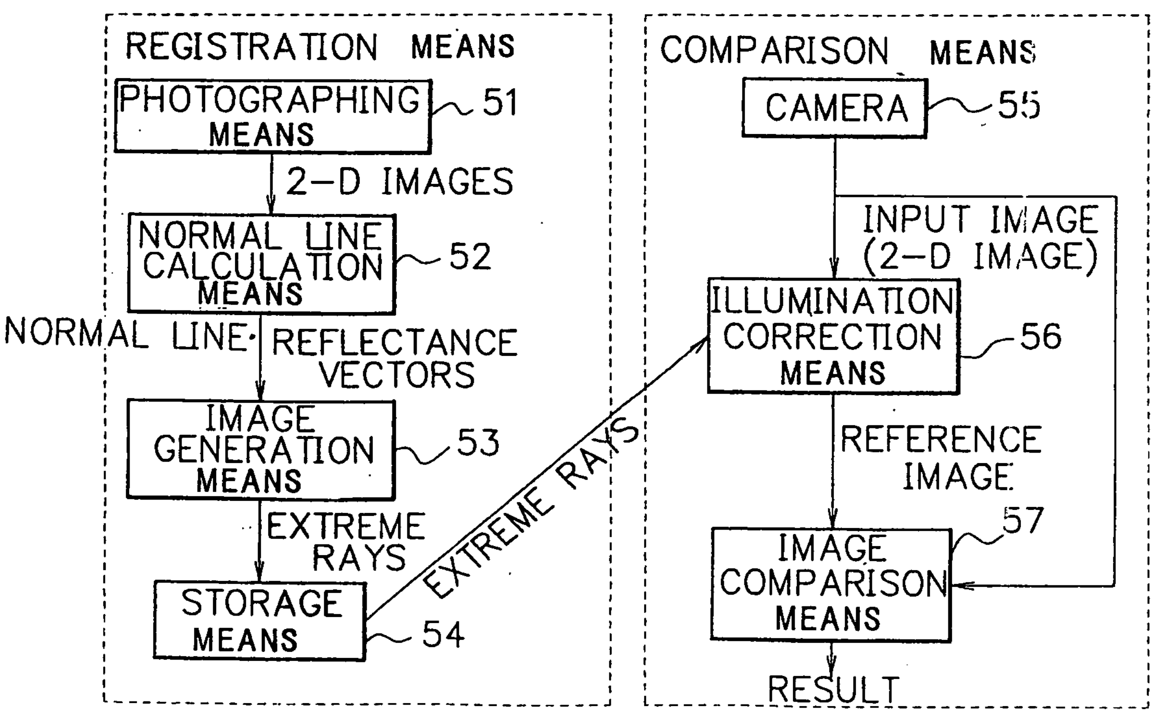

STANDARD 3-D SHAPE
REGISTRATION MEANS
CAMERA
41
2-D IMAGE
FEATURE EXTRACTION MEANS
42
FEATURE POINT POSITIONS
STORAGE MEANS
43
FEATURE POINT POSITIONS
COMPARISON MEANS
CAMERA
44
2-D IMAGE
FEATURE EXTRACTION MEANS
45
FEATURE POINT POSITIONS
POSITION/POSE NORMALIZATION MEANS
46
FEATURE POINT POSITIONS
COMPARISON MEANS
47
RESULT

FIG. 16



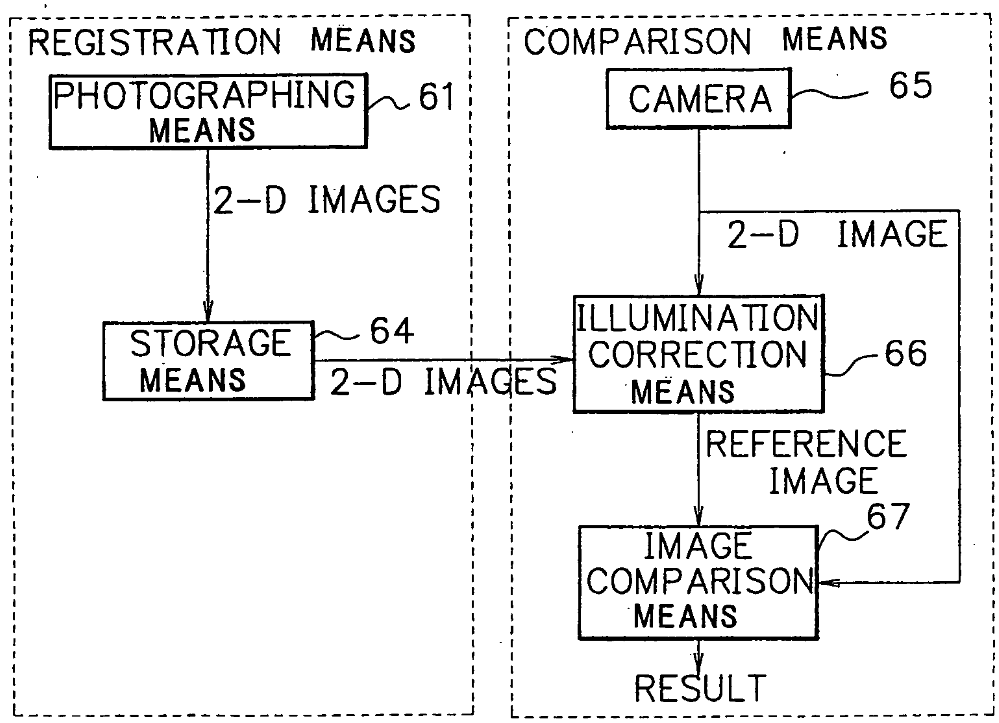
REGISTRATION MEANS
PHOTOGRAPHING MEANS
71
2-D IMAGES
MANIFOLD CALCULATION MEANS
72
BASIS VECTORS MANIFOLD
STORAGE MEANS
73
BASIS VECTORS MANIFOLD
COMPARISON MEANS
CAMERA
74
2-D IMAGE
DISTANCE CALCULATION MEANS
75
RESULT

FIG. 17



REGISTRATION MEANS
PHOTOGRAPHING MEANS
51
2-D IMAGES
NORMAL LINE CALCULATION MEANS
52
NORMAL LINE· REFLECTANCE VECTORS
IMAGE GENERATION MEANS
53
EXTREME RAYS
STORAGE MEANS
54
EXTREME RAYS
COMPARISON MEANS
CAMERA
55
INPUT IMAGE (2-D IMAGE)
ILLUMINATION CORRECTION MEANS
56
REFERENCE IMAGE
IMAGE COMPARISON MEANS
57
RESULT

FIG. 18



REGISTRATION MEANS
PHOTOGRAPHING MEANS
61
2-D IMAGES
STORAGE MEANS
64
2-D IMAGES
COMPARISON MEANS
CAMERA
65
2-D IMAGE
ILLUMINATION CORRECTION MEANS
66
REFERENCE IMAGE
67
IMAGE COMPARISON MEANS
RESULT

業務発明届出・譲渡・意見書

（ＮＥＣ単独出願）

【発明者記入欄】

[redacted]

仮番号	11228721	発明の名称　画像照合方法、装置、および記憶媒体
整理番号	335-09734	

発明者						
	確認	会社コード 社員番号	氏名 ローマ字（外国出願に用いるため）	電話　地区一番号 外線ダイヤルイン	Ｅメールアドレス 外線ＦＡＸ番号	会社名 所属部門名
1	済	0000 1019278	石山 塁 ISHIYAMA Rui	272-3700 044(856)2145	rui@ccm.cl.nec.co.jp 044(856)2236	日本電気株式会社 Ｃ＆Ｃメディア研究所

届出の形態	○発明説明書（実施の形態・図面等）による届出 ●明細書全文による届出 ○コンカレント	
外国出願	●希望する ○希望しない	出願希望国　アメリカ　イギリス　ドイツ
国内優先権主張	○自発的 ○知的財産部の要請 ●希望しない	先の発明の出願番号 先の発明の出願日　　年　月　日（西暦８桁で記入のこと） 先の発明の整理番号　－ 知的財産部要請日　　年　月　日（西暦８桁で記入のこと）
社外発表出荷予定	○製品発表 ●論文発表 ○新聞発表 ○その他 ○社外発表なし	製品名 学会名　電子情報通信学会ＰＲＭＵ研究会 発表予定日 [redacted]（西暦８桁で記入のこと）
	□製品出荷	製品出荷先 出荷予定日　年　月　日（西暦８桁で記入のこと）
関連発明（あれば入力）	出願番号 出願日　　年　月　日（西暦８桁で記入のこと） 整理番号　－ 外国出願してあればその国名	
発明の種類	○ビジネスの方法（やり方や仕組み）に関する発明である ●その他の発明である	

譲　渡

上記の発明について、日本電気株式会社従業員就業規則にもとづいて、 特許または実用新案登録を受ける権利を日本電気株式会社に譲渡いたします。

Notification of employee's invention · Assignment · Opinion
(Application by NEC only)

【Entry space for inventor】

[redacted]

Provisional No.	11228721	Title of the invention DEVICE, METHOD AND RECORD MEDIUM FOR IMAGE COMPARISON
Reference No.	335-09734	

Inventor						
	Confirmation	Company Code Employee No.	Name	Telephone number	e-mail address FAX number	Company Current department
1	Done	0000 1019278	Rui ISHIYAMA	272-3700 044(856)2145	rui@ccm.cl.nec.co.jp 044(856)2236	NEC Corporation C&C media laboratory

Form of notification	○ notification by invention report (embodiments, drawings, etc.) ● notification by completed specification ○ concurrent	
Foreign application	● desired ○ not desired	Country: US GB DE
National priority	○ voluntary ○ requested by intellectual property dept. ● not desired	Application No. of the prior invention: Application date of the prior invention (Fill in by 8 figures in dominical year form): Reference No. of the prior invention: Date of request (Fill in by 8 figures in dominical year form):
Schedule for external publication or shipment	○ publication of products ● publication of papers ○ publication through newspaper ○ other ○ no external publication	Product name: Name of academic conference: The Institute of Electronics, Information and Communication Engineers, PRMU forum Expected date for publication (Fill in by 8 figures in dominical year form): May 11, 2000
	☐ shipment	Ship-to: Expected date for shipment (Fill in by 8 figures in dominical year form):
Related invention (if any)	Application No.: Application date: Reference No.: Country if foreign application has been filed:	
Type of invention	○ business model (method or structure) ● others	

Assignment

I assign the right to obtain a patent or a utility design concerning the above invention to NEC Corporation based on the employee regulation of NEC Corporation.

[redacted]

丸山特許事務所
丸山　隆夫　　　　　様

日 本 電 気 株 式 会 社
知的財産部長 京本　直樹

特許出願のご依頼

拝啓　時下ますますご清栄のこととお喜び申し上げます。

さて、貴幣間で締結の委任業務契約書第２条に基づき、下記のとおり出願をご手配くださるようお願い申し上げます。

敬具

記

1．依頼発明

依頼番号	０８４２５－０１３０６
整理番号	３３５０９７３４
審査請求	保留
出願種別	通常
出願人形態	ＮＥＣ単独
外国出願	外国出願する
Ｓ指定	なし
出願人	会社名　日本電気株式会社　／　識別番号　０００００４２３７
出願期限	[redacted]
当部技術担当者	齊藤　　浩孝
届出区分	新：出願直前の明細書点検が必要
届出の形態	明細書全文による届出

2．納品

出願後、一両日中に電子納品でお願いします。

3．その他

①ＪＩＳ１０出願の場合は出願番号通知書を入手後直ちに出願番号入力を行ってください。

以下の書類はＷＷＷにてご確認ください。

１．業務発明届出・譲渡書

２．発明説明書（または届出明細書）および図面の草案

３．先行技術文献

４．明細書作成方針ご連絡メモ

以上

研究開発技術本部

情報特許部

齊藤　浩孝　　Ｅ－Ｍａｉｌ：saitoh@nppi.cl.nec.co.jp

Ｔ　Ｅ　Ｌ：044(856)2052

Ｆ　Ａ　Ｘ：

[redacted]

Maruyama Patent Office

Mr. Takao MARUYAMA

NEC Corporation

Manager of Intellectual Property Department

Naoki KYOMOTO

Request for Patent Application

Dear Sir,

According to Article 2 of the Contract for entrusted practice, we request you to arrange a patent application as shown below.

1. Invention

Request number	08425-01306
Reference number	33509734
Request for examination	Reserved
Application type	Normal
Form of applicant	NEC only
Foreign application	Yes
S-assignment	No
Applicant	Company name NEC Corporation Identification number 000004237
Time limit for application	[redacted]
Peron in charge at this department	Hirotaka SAITOH
Notification type	New: Review of the specification prior to the filing is needed.
Notification form	Completed specification

2. Delivery

Please proceed to electronic delivery in couple of days after the filing.

3. Other

① In the case of JIS10 application, kindly input the application number immediately after you receive the notification of application number.

Please review the following documents on the WWW.

1. Notification of employee's invention, Assignment
2. Invention Report (or notified specification) and draft figures
3. Prior art documents
4. Instruction on the drafting of a specification

Research and development head office

Patent Section

Hirotaka SAITOH E-Mail: saitoh@nppi.cl.nec.co.jp

Tel: 044(856)2052

FAX:

＜整理番号：335-09734　出願番号：特願2000-105309＞

CLR	文書名	種別・公報番号	庁発送日	庁提出日	文書登録日	ページ数
☑	サーチレポート（読み方）				[redacted]	
☐		特開平06-236435			[redacted]	0015
☐		特開平09-259271			[redacted]	0006
☐		特開平10-132529			[redacted]	0010
☐		特開平10-232931			[redacted]	0008
CLR	文書名	種別・公報番号	庁発送日	庁提出日	文書登録日	ページ数
☐	明細書				[redacted]	
☐	業務発明届出譲渡書・意見書				[redacted]	
☐	明細書作成方針ご連絡メモ				[redacted]	
☐	出願明細書原稿				[redacted]	
☐	出願明細書原稿（発明者）				[redacted]	
CLR	文書名	種別・公報番号	庁発送日	庁提出日	文書登録日	ページ数
☐	出願明細注文書				[redacted]	
☐	出願明細・図面			[redacted]	[redacted]	0093
☐	出願要約書			[redacted]	[redacted]	0001
☐	願書（PCT国内移行書面・意匠含む）			[redacted]	[redacted]	0001
☐	公開公報	特開2001-283216			[redacted]	0033
CLR	文書名	種別・公報番号	庁発送日	庁提出日	文書登録日	ページ数
☐	引用例・公知例	特開平06-168317			[redacted]	0007
☐	引用例・公知例	特開平04-101280			[redacted]	0005
	引用例・公知例	文献			[redacted]	0020

<整理番号:335-09734 出願番号:特願2000-105399>

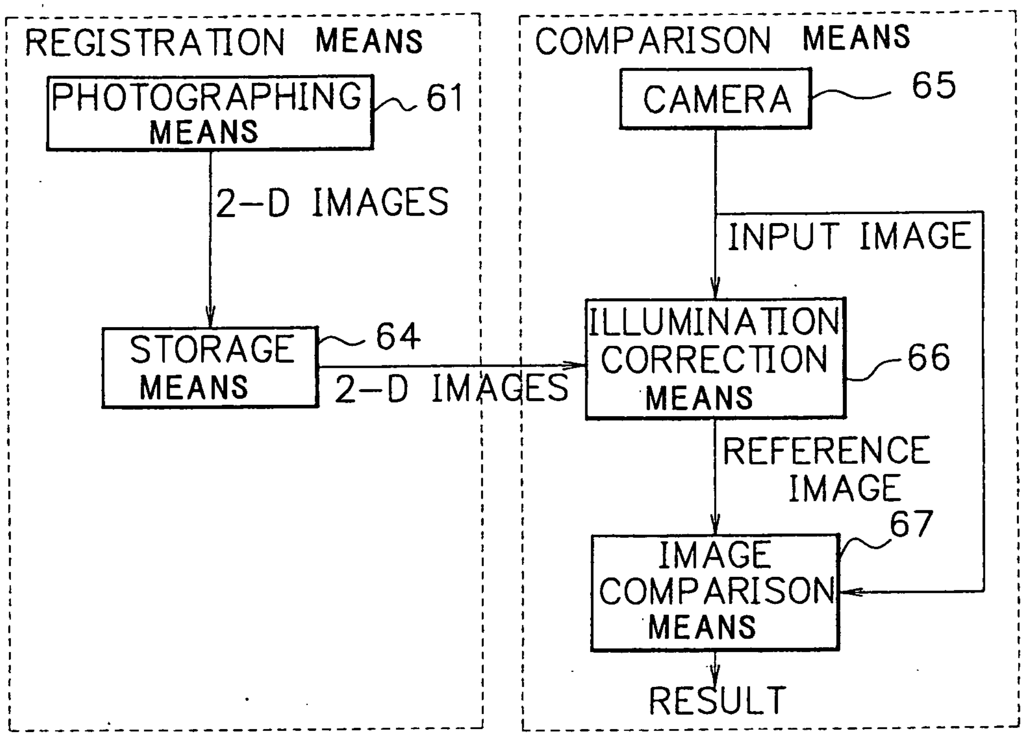
	CLR	文書名	種別・公報番号	庁発送日	庁提出日	文書登録日	ページ数
ⓒ→	☑	サーチレポート (読み方)				[redacted]	
	☐		特開平08-236435			[redacted]	0015
	☐		特開平09-259271			[redacted]	0006
	☐		特開平10-132529			[redacted]	0010
	☐		特開平10-232931			[redacted]	0006
	CLR	文書名	種別・公報番号	庁発送日	庁提出日	文書登録日	ページ数
	☐	明細書				[redacted]	
	☐	業務発明届出譲渡書・意見書				[redacted]	
	☐	明細書作成方針ご連絡メモ				[redacted]	
ⓐ→	☐	出願明細書原稿				2000.03.28	
ⓑ→	☐	出願明細書原稿(発明者)				2000.03.30	
	CLR	文書名	種別・公報番号	庁発送日	庁提出日	文書登録日	ページ数
	☐	出願明細法文書				[redacted]	
	☐	出願明細・図面			[redacted]	[redacted]	0093
	☐	出願要約書			[redacted]	[redacted]	0001
	☐	願書(PCT国内移行書面・委任含む)			[redacted]	[redacted]	0001
	☐	公開公報	特開2001-283216			[redacted]	0033
	CLR	文書名	種別・公報番号	庁発送日	庁提出日	文書登録日	ページ数
	☐	引用例・公知例	特開平06-168317			[redacted]	0007
	☐	引用例・公知例	特開平04-101280			[redacted]	0005
		引用例・公知例	文献			[redacted]	0020

← Inventor's original specification (document (a))

Notification of employee's invention (document (b))

Request for patent application (document (c))

FIG. 18



REGISTRATION MEANS
PHOTOGRAPHING MEANS
61
2-D IMAGES
STORAGE MEANS
64
2-D IMAGES
COMPARISON MEANS
CAMERA
65
INPUT IMAGE
ILLUMINATION CORRECTION MEANS
66
REFERENCE IMAGE
67
IMAGE COMPARISON MEANS
RESULT

DECLARATION

I, Takao MARUYAMA, a Japanese Patent Attorney registered No. 8425, having my business office at SAM Bldg., 38-23, Higashi-Ikebukuro 2-chome, Toshima-ku, Tokyo 170-0013, Japan, solemnly and sincerely declare that I have a thorough knowledge of Japanese and English languages, that I made an English translation attached hereto, and that to the best of my knowledge and belief the translation is a true and correct reproduction of the original documents filed with the Japanese Patent Office in respect of Japanese Patent Application No. 2000-105399 on April 3, 2000 in the name of NEC Corporation.

Signed this 10th day of May, 2006

Takao Maruyama

Patent Attorney

PATENT OFFICE

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This is to certify that the annexed is a true copy of the following application as filed with this Office.

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[Title of Object] Drawings 1

[Title of Object] Abstract 1

[Number of Inclusive Power of Attorney] 9303564

[Title of Document] Specification

[Title of Invention] DEVICE, METHOD AND RECORD MEDIUM FOR IMAGE COMPARISON

[Scope of Claim for Patent]

[Claim 1] An image comparison device comprising:

a registration means for registering data of a registration target object as three-dimensional data; and

a comparison means for obtaining, two-dimensional data of an object to be compared with the data registered in the registration means and comparing the obtained data with the data of the registered object in the registration means.

[Claim 2] The image comparison device as claimed in claim 1, wherein the comparison means includes:

a photographing means for photographing, as an input image, the target object to be compared with the data of registered objects registered in the registration means;

a position/pose correction means for correcting the position/pose of the target object obtained by the photographing means;

an illumination correction means for generating, as a reference image, an image in the same position/pose as the input image, which is photographed by the photographing means, and under an illumination condition most similar to that of the input image by use of the position/pose corrected by the position/pose correction means and the data registered in the registration means;

an image comparison means for comparing the reference image generated by the illumination correction means with the input image obtained by the photographing means and thereby calculating an evaluation value concerning the similarity between the two images; and

a comparison judgment means for judging whether or not the target object photographed by the photographing means is the registered

object registered in the registration means based on the evaluation value calculated by the image comparison means.

[Claim 3] The image comparison device as claimed in claim 2, wherein the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement means for measuring the surface reflectance at each position on the three-dimensional shape of the object to be registered; and

a data storage means for storing, as the registered data, the three-dimensional shapes measured by the three-dimensional shape measurement means and the reflectance measured by the reflectance measurement means.

[Claim 4] The image comparison device as claimed in claim 2, wherein the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

an image information obtaining means for obtaining image information of the object by photographing the object to be registered; and

a data storage means for storing, as the registered data, the three-dimensional shapes measured by the three-dimensional shape measurement means and the image information obtained by the image information obtaining means.

[Claim 5] The image comparison device as claimed in claim 2, wherein the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

an average shape generation means for generating an average three-dimensional shape of the three-dimensional shapes measured by

the three-dimensional shape measurement means when registering a plurality of objects;

a reflectance measurement means for measuring the surface reflectance at each position of the three-dimensional shape of the object to be registered; and

a data storage means for storing, as the registered data, the three-dimensional shape measured by the three-dimensional shape measurement means, the average three-dimensional shape generated by the average shape generation means and the reflectance measured by the reflectance measurement means.

[Claim 6] The image comparison device as claimed in one of claims 3 to 5, wherein the illumination correction means includes:

an image generation means for generating, as illumination variation images, images of each object in the same position/pose as the object photographed by the photographing means and under various illumination conditions by use of the position/pose corrected by the position/pose correction means and the registered data of objects in the registration means; and

an illumination condition estimation means for generating an image that is the most similar to the input image obtained by the photographing means by use of the illumination variation images generated by the image generation means and outputting the generated image to the image comparison means as the reference image.

[Claim 7] The image comparison device as claimed in claim 6, wherein:

the illumination correction means further includes an illumination variation space generation means for generating an illumination variation space which is spanned by the illumination variation images generated by the image generation means, and

the illumination condition estimation means generates the

image that is the most similar to the input image from the illumination variation space generated by the illumination variation space generation means and outputs the generated image to the image comparison means as the reference image.

[Claim 8] The image comparison device as claimed in claim 7, wherein:

the illumination variation space generation means generates basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting principal component analysis to the illumination variation images generated by the image generation means, and

the illumination condition estimation means obtains correlations between the input image obtained by the photographing means and each of the basis vectors generated by the illumination variation space generation means, generates the image that is the most similar to the input image by use of the basis vectors and based on the correlations, and outputs the generated image to the image comparison means as the reference image.

[Claim 9] The image comparison device as claimed in one of claims 6 to 8, wherein the illumination correction means further includes an illumination condition variation means for setting various illumination conditions and outputting the illumination conditions to the image generation means.

[Claim 10] The image comparison device as claimed in claim 2, wherein:

the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each registered object;

a texture image photographing means for photographing the object to be registered under various illumination conditions and thereby

obtaining texture images of the registered object; and

a data storage means for storing the three-dimensional shapes measured by the three-dimensional shape measurement means and the texture images obtained by the texture image photographing means as the registered data, and

the illumination correction means includes:

an image generation means for generating illumination variation images of each object in the same position/pose as the object photographed by the photographing means by use of the position/pose determined by the position/pose determination means and the three-dimensional shapes and the texture images of the object registered in the registration means; and

an illumination condition estimation means for generating an image that is the most similar to the input image obtained by the photographing means by use of the illumination variation images generated by the image generation means and outputting the generated image to the image comparison means as the reference image.

[Claim 11] The image comparison device as claimed in claim 10, wherein the illumination correction means further includes an illumination variation space generation means for generating an illumination variation space which is spanned by the illumination variation images generated by the image generation means, and

the illumination condition estimation means generates the image that is the most similar to the input image from the illumination variation space generated by the illumination variation space generation means and outputs the generated image to the image comparison means as the reference image.

[Claim 12] The image comparison device as claimed in claim 11, wherein:

the illumination variation space generation means generates

basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting the principal component analysis to the illumination variation images generated by the image generation means, and

the illumination condition estimation means obtains correlations between the input image obtained by the photographing means and each of the basis vectors generated by the illumination variation space generation means, generates the image that is the most similar to the input image by use of the basis vectors and based on the correlations, and outputs the generated image to the image comparison means as the reference image.

[Claim 13] The image comparison device as claimed in claim 2, wherein the position/pose correction means outputs a predetermined position/pose to the illumination correction means.

[Claim 14] The image comparison device as claimed in claim 2, wherein the position/pose correction means receives inputs concerning position/pose parameters of the object in the input image obtained by the photographing means, and outputs the received position/pose to the illumination correction means.

[Claim 15] The image comparison device as claimed in claim 2, wherein the position/pose correction means estimates the position/pose of the object in the input image obtained by the photographing means, and outputs the estimated position/pose to the illumination correction means.

[Claim 16] The image comparison device as claimed in claim 15, wherein:

the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement means for measuring the surface reflectance at each position of the three-dimensional shape of the object

to be registered;

a first feature point extraction means for extracting feature point positions based on the three-dimensional shape measured by the three-dimensional shape measurement means and the reflectance measured by the reflectance measurement means; and

a data storage means for storing the three-dimensional shapes measured by the three-dimensional shape measurement means, the reflectance measured by the reflectance measurement means and the feature point positions obtained by the first feature point extraction means as the registered data, and

the position/pose correction means includes:

a second feature point extraction means for extracting, from the input image obtained by the photographing means, input image feature point positions being the same feature point positions as those stored in the storage means; and

a position/pose calculation means for estimating the position/pose of the object photographed by the photographing means based on the three-dimensional shape and the feature point positions stored in the data storage means and the input image feature point positions extracted by the second feature point extraction means and outputting the estimated position/pose to the illumination correction means.

[Claim 17] The image comparison device as claimed in claim 16, wherein the illumination correction means includes:

an image generation means for generating images of each object in the same position/pose as the object photographed by the photographing means and under various illumination conditions as illumination variation images by use of the position/pose estimated by the position/pose correction means and the three-dimensional shape and the reflectance stored in the data storage means; and

an illumination condition estimation means for generating an image that is the most similar to the input image obtained by the photographing means by use of the illumination variation images generated by the image generation means and outputting the generated image to the image comparison means as the reference image.

[Claim 18] The image comparison device as claimed in claim 17, wherein:

the illumination correction means further includes an illumination variation space generation means for generating an illumination variation space which is spanned by the illumination variation images generated by the image generation means, and

the illumination condition estimation means generates the image that is the most similar to the input image from the illumination variation space generated by the illumination variation space generation means and outputs the generated image to the image comparison means as the reference image.

[Claim 19] The image comparison device as claimed in claim 18, wherein:

the illumination variation space generation means generates basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting principal component analysis to the illumination variation images generated by the image generation means, and

the illumination condition estimation means obtains correlations between the input image obtained by the photographing means and each of the basis vectors generated by the illumination variation space generation means, generates the image that is the most similar to the input image photographed by the photographing means by use of the basis vectors and based on the correlations, and outputs the generated image to the image comparison means as the reference image.

[Claim 20] The image comparison device as claimed in one of claims 17 to 19, wherein the illumination correction means further includes an illumination condition variation means for setting various illumination conditions and outputting the illumination conditions to the image generation means.

[Claim 21] The image comparison device as claimed in claim 1, wherein:

the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement means for measuring the surface reflectance at each position of the three-dimensional shape of the object to be registered;

an image generation means for generating images of each object to be registered under various illumination conditions as illumination variation images;

an illumination variation space generation means for generating an illumination variation space which is spanned by the illumination variation images generated by the image generation means; and

a data storage means for storing the illumination variation space generated by the illumination variation space generation means as the registered data, and

the comparison means includes:

a photographing means for photographing, as an input image, the target object to be compared with the data of registered objects registered in the registration means;

an illumination condition estimation means for generating, as a reference image, the image that is the most similar to the input image from the illumination variation space stored in the data storage means;

an image comparison means for comparing each reference image

generated by the illumination condition estimation means with the input image obtained by the photographing means and thereby calculating an evaluation value concerning the similarity between the two images; and

a comparison judgment means for judging whether or not each of the registered objects registered in the registration means is the object photographed by the photographing means based on the evaluation value calculated by the image comparison means.

[Claim 22] The image comparison device as claimed in claim 1, wherein:

the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement means for measuring the surface reflectance at each position of the three-dimensional shape of the object to be registered;

an image generation means for generating images of each object to be registered under various illumination conditions as illumination variation images;

an illumination variation space generation means for generating basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting principal component analysis to the illumination variation images generated by the image generation means; and

a data storage means for storing, as the registered data, the basis vectors generated by the illumination variation space generation means, and

the comparison means includes:

a photographing means for photographing, as an input image, the target object to be compared with the data of registered objects registered in the registration means;

an illumination condition estimation means for obtaining correlations between the input image obtained by the photographing means and each of the basis vectors stored in the data storage means, generating, as the reference image, the image that is the most similar to the input image by use of the basis vectors and based on the correlations;

an image comparison means for comparing each reference image generated by the illumination condition estimation means with the input image obtained by the photographing means and thereby calculating an evaluation value concerning the similarity between the two images; and

a comparison judgment means for judging whether or not each of the registered objects registered in the registration means is the object photographed by the photographing means based on the evaluation value calculated by the image comparison means.

[Claim 23] The image comparison device as claimed in one of claims 2 to 22, wherein the three-dimensional shape measurement means measures the three-dimensional shapes by reading data or drawings.

[Claim 24] The image comparison device as claimed in one of claims 2 to 23, wherein the reflectance measurement means obtains the reflectance by reading data or drawings.

[Claim 25] The image comparison device as claimed in one of claims 2 to 24, wherein the photographing means obtains the input image by scanning a film, a photograph or printed matter.

[Claim 26] The image comparison device as claimed in one of claims 2 to 25, wherein the comparison judgment means judges which registered object matches the target object.

[Claim 27] The image comparison device as claimed in one of claims 2 to 26, wherein the comparison judgment means searches for one or more registered objects that are similar to the target object.

[Claim 28] The image comparison device as claimed in one of

claims 1 to 27, wherein the registered objects are automobiles.

[Claim 29] The image comparison device as claimed in one of claims 1 to 28, wherein the objects to be registered are human faces.

[Claim 30] An image comparison method comprising the steps of:

a registration step in which three-dimensional data of each object to be registered are registered; and

a comparison step in which two-dimensional data of an object to be compared with the data registered in the registration step is obtained, and the obtained data is compared with the data registered in the registration step.

[Claim 31] The image comparison method as claimed in claim 30, wherein the comparison step includes:

a photographing step in which the comparison target object is photographed and thereby an input image is obtained;

a position/pose correction step in which the position/pose of the target object obtained in the photographing step is corrected;

an illumination correction step in which an image of each registered object in the same position/pose as the target object in the input image and under an illumination condition most similar to that of the input image is obtained as a reference image by use of the position/pose corrected in the position/pose correction step and the data registered in the registration step;

an image comparison step in which each reference image generated in the image correction step is compared with the input image obtained in the photographing step and thereby an evaluation value concerning the similarity between the two images is calculated; and

a comparison judgment step in which it is judged whether or not each registered object registered in the registration step is the object photographed in the photographing step based on the evaluation value calculated in the image comparison step.

[Claim 32] The image comparison method as claimed in claim 31, wherein the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement step in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured; and

a data storage step in which the three-dimensional shapes measured in the three-dimensional shape measurement step and the reflectance measured in the reflectance measurement step are stored as the registered data.

[Claim 33] The image comparison method as claimed in claim 31, wherein the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

a image information obtaining step in which the object to be registered is photographed and thereby image information of the object to be registered is obtained; and

a data storage step in which the three-dimensional shape measured in the three-dimensional shape measurement step and the image information obtained in the image obtaining step are stored as the registered data.

[Claim 34] The image comparison method as claimed in claim 31, wherein the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

an average shape generation step in which an average three-dimensional shape is generated as the average of a plurality of the three-dimensional shapes measured in the three-dimensional shape measurement step when registering a plurality of objects;

a reflectance measurement step in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured; and

a data storage step in which the three-dimensional shapes measured in the three-dimensional shape measurement step, the average three-dimensional shape generated in the average shape generation step and the reflectance measured in the reflectance measurement step are stored as the registered data.

[Claim 35] The image comparison method as claimed in one of claims 32 to 34, wherein the illumination correction step includes:

an image generation step in which images of each registered object in the same position/pose as the target object photographed by the photographing means and under various illumination conditions are generated as illumination variation images by use of the position/pose corrected in the position/pose correction step and the data registered in the registration step; and

an illumination condition estimation step in which an image that is the most similar to the input image obtained in the photographing step is generated as the reference image by use of the illumination variation images generated in the image generation step.

[Claim 36] The image comparison method as claimed in claim 35, wherein:

the illumination correction step further includes an illumination variation space generation step in which an illumination variation space which is spanned by the illumination variation images generated in the image generation step is generated, and

in the illumination condition estimation step, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation step.

[Claim 37] The image comparison method as claimed in claim 36, wherein:

in the illumination variation space generation step, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting principal component analysis to the illumination variation images generated in the image generation step, and

in the illumination condition estimation step, correlations are obtained between the input image obtained in the photographing step and each of the basis vectors generated in the illumination variation space generation step, and the image that is the most similar to the input image is generated as the reference image by use of the basis vectors and based on the correlations.

[Claim 38] The image comparison method as claimed in one of claims 35 to 37, wherein the illumination correction step further includes an illumination condition variation step in which various illumination conditions are set and generated to be used for generating illumination variation images before the illumination variation images are generated in the image generation step.

[Claim 39] The image comparison method as claimed in claim 31, wherein:

the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

a texture image photographing step in which the object to be registered is photographed under various illumination conditions and thereby texture images are obtained; and

a data storage step in which the three-dimensional shapes measured in the three-dimensional shape measurement step and the texture images obtained in the texture image photographing step are

stored as the registered data, and

the illumination correction step includes:

an image generation step in which illumination variation images of each registered object in the same position/pose as the target object in the input image and under various illumination conditions are generated by use of the position/pose corrected in the position/pose correction step and the three-dimensional shapes and the texture images of the object stored in the storage step; and

an illumination condition estimation step in which an image that is the most similar to the input image obtained in the photographing step is generated as the reference image by use of the illumination variation images generated in the image generation step.

[Claim 40] The image comparison method as claimed in claim 39, wherein the illumination correction step further includes an illumination variation space generation step in which an illumination variation space which is spanned by the illumination variation images generated in the image generation step is generated before the reference image is generated in the illumination condition estimation step, and

in the illumination condition estimation step, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation step.

[Claim 41] The image comparison method as claimed in claim 40, wherein:

in the illumination variation space generation step, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting the principal component analysis to the illumination variation images generated in the image generation step, and

in the illumination condition estimation step, correlations are

obtained between the input image obtained in the photographing step and each of the basis vectors generated in the illumination variation space generation step, and the image that is the most similar to the input image is generated as the reference image by use of the basis vectors and based on the correlations.

[Claim 42] The image comparison method as claimed in claim 31, wherein in the position/pose correction step, the position/pose of the object is the corrected position/pose of a predetermined position/pose.

[Claim 43] The image comparison method as claimed in claim 31, wherein in the position/pose correction step, the position/pose is a corrected position/pose to which position/pose parameters of the object photographed by the photographing means are input.

[Claim 44] The image comparison method as claimed in claim 31, wherein in the position/pose correction step, the position/pose is a corrected position/pose of the estimated position/pose of the object photographed by the photographing means.

[Claim 45] The image comparison method as claimed in claim 44, wherein:

the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement step in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured;

a first feature point extraction step in which feature point positions of the registered object are extracted based on the three-dimensional shape measured in the three-dimensional shape measurement step and the reflectance measured in the reflectance measurement step; and

a data storage step in which the three-dimensional shapes

measured in the three-dimensional shape measurement step, the reflectance measured in the reflectance measurement step and the feature point positions extracted in the first feature point extraction step are stored as the registered data, and

the position/pose correction step includes:

a second feature point extraction step in which feature point positions same as those stored in the data storage step are extracted from the input image obtained in the photographing step as input image feature point positions; and

a position/pose calculation step in which the position/pose of the object photographed in the photographing means is estimated based on the three-dimensional shape and the feature point positions stored in the data storage step and the input image feature point positions obtained in the second feature point extraction step.

[Claim 46] The image comparison method as claimed in claim 45, wherein the illumination correction step includes:

an image generation step in which images of each object in the same position/pose as the object obtained in the photographing step and under various illumination conditions are generated as illumination variation images by use of the position/pose estimated in the position/pose determination step and the three-dimensional shape and the reflectance stored in the data storage step; and

an illumination condition estimation step in which an image that is the most similar to the input image obtained in the photographing step is generated as the reference image by use of the illumination variation images generated in the image generation step.

[Claim 47] The image comparison method as claimed in claim 46, wherein:

the illumination correction step further includes an illumination variation space generation step in which an illumination variation space

which is spanned by the illumination variation images generated in the image generation step is generated before the reference image is generated in the illumination condition estimation step, and

in the illumination condition estimation step, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation step.

[Claim 48] The image comparison method as claimed in claim 47, wherein:

in the illumination variation space generation step, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting principal component analysis to the illumination variation images generated in the image generation step, and

in the illumination condition estimation step, correlations are obtained between the input image obtained in the photographing step and each of the basis vectors generated in the illumination variation space generation step, and the image that is the most similar to the input image obtained in the photographing step is generated as the reference image by use of the basis vectors and based on the correlations.

[Claim 49] The image comparison method as claimed in one of claims 46 to 48, wherein the illumination correction step further includes an illumination condition variation step in which various illumination conditions are set and generated before illumination variation images are generated in the image generation step.

[Claim 50] The image comparison method as claimed in claim 30, wherein:

the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement step in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured;

an image generation step in which images of each object to be registered under various illumination conditions are generated as illumination variation images;

an illumination variation space generation step in which an illumination variation space which is spanned by the illumination variation images generated in the image generation step is generated; and

a data storage step in which the illumination variation space generated in the illumination variation space generation step is stored as the registered data, and

the comparison step includes:

a photographing step in which the comparison target object to be compared with the registered object registered in the registration step is photographed as an input image is obtained;

an illumination condition estimation step in which an image of each object that is the most similar to the input image obtained in the photographing step is generated as a reference image from the illumination variation space stored in the data storage step;

an image comparison step in which each reference image generated in the illumination condition estimation step is compared with the input image obtained in the photographing step and thereby an evaluation value concerning the similarity between the two images is calculated; and

a comparison judgment step in which it is judged whether or not each of the registered objects registered in the registration step is the target object photographed in the photographing step based on the evaluation value calculated in the image comparison step.

[Claim 51] The image comparison method as claimed in claim 30, wherein:

the registration step includes:

a three-dimensional shape measurement step for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement step for measuring the surface reflectance at each position of the three-dimensional shape of the object to be registered;

an image generation step for generating images of each object to be registered under various illumination conditions as illumination variation images;

an illumination variation space generation step for generating basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting principal component analysis to the illumination variation images generated in the image generation step; and

a data storage step for storing, as the registered data, the basis vectors generated by the illumination variation space generation step, and

the comparison step includes:

a photographing step for photographing, as an input image, the target object to be compared with the data of registered objects registered in the registration step;

an illumination condition estimation step for obtaining correlations between the input image obtained by the photographing step and each of the basis vectors stored in the data storage step, generating, as the reference image, the image that is the most similar to the input image by use of the basis vectors and based on the correlations;

an image comparison step for comparing each reference image generated by the illumination condition estimation step with the input

image obtained by the photographing step and thereby calculating an evaluation value concerning the similarity between the two images; and

a comparison judgment step for judging whether or not each of the registered objects registered in the registration step is the object photographed by the photographing step based on the evaluation value calculated by the image comparison step.

[Claim 52] The image comparison method as claimed in one of claims 31 to 51, wherein the three-dimensional shape measurement step measures the three-dimensional shapes by reading data or drawings.

[Claim 53] The image comparison method as claimed in one of claims 31 to 52, wherein the reflectance measurement step obtains the reflectance by reading data or drawings.

[Claim 54] The image comparison method as claimed in one of claims 31 to 53, wherein the photographing step obtains the input image by scanning a film, a photograph or printed matter.

[Claim 55] The image comparison method as claimed in one of claims 31 to 54, wherein the comparison judgment step judges which registered object matches the target object.

[Claim 56] The image comparison method as claimed in one of claims 31 to 55, wherein the comparison judgment step searches for one or more registered objects that are similar to the target object.

[Claim 57] The image comparison method as claimed in one of claims 30 to 56, wherein the registered objects are automobiles.

[Claim 58] The image comparison method as claimed in one of claims 30 to 57, wherein the objects to be registered are human faces.

[Claim 59] A record medium storing an image comparison program executing the processes of:

a registration process in which three-dimensional data of each object to be registered are registered; and

a comparison process in which two-dimensional data of an object

to be compared with the data registered in the registration step is obtained, and the obtained data is compared with the data registered in the registration process.

[Claim 60] A record medium storing the image comparison program as claimed in claim 59, wherein the comparison process executes the processes of:

a photographing process in which the comparison target object is photographed and thereby an input image is obtained;

a position/pose correction process in which the position/pose of the target object obtained in the photographing process is corrected;

an illumination correction process in which an image of each registered object in the same position/pose as the target object in the input image and under an illumination condition most similar to that of the input image is obtained as a reference image by use of the position/pose corrected in the position/pose correction process and the data registered in the registration process;

an image comparison process in which each reference image generated in the image correction process is compared with the input image obtained in the photographing process and thereby an evaluation value concerning the similarity between the two images is calculated; and

a comparison judgment process in which it is judged whether or not each registered object registered in the registration process is the object photographed in the photographing process based on the evaluation value calculated in the image comparison process.

[Claim 61] A record medium storing the image comparison program as claimed in claim 60, wherein the registration process executes the processes of:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement process in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured; and

a data storage process in which the three-dimensional shapes measured in the three-dimensional shape measurement process and the reflectance measured in the reflectance measurement process are stored as the registered data.

[Claim 62] A record medium storing the image comparison program as claimed in claim 60, wherein the registration process executes the processes of:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

a image information obtaining process in which the object to be registered is photographed and thereby image information of the object to be registered is obtained; and

a data storage process in which the three-dimensional shape measured in the three-dimensional shape measurement process and the image information obtained in the image obtaining process are stored as the registered data.

[Claim 63] A record medium storing the image comparison program as claimed in claim 60, wherein the registration process executes the processes of:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

an average shape generation process in which an average three-dimensional shape is generated as the average of a plurality of the three-dimensional shapes measured in the three-dimensional shape measurement process when registering a plurality of objects;

a reflectance measurement process in which the surface reflectance at each position of the three-dimensional shape of the object

to be registered is measured; and

a data storage process in which the three-dimensional shapes measured in the three-dimensional shape measurement process, the average three-dimensional shape generated in the average shape generation process and the reflectance measured in the reflectance measurement process are stored as the registered data.

[Claim 64] A record medium storing the image comparison program as claimed in one of claims 61 to 63, wherein the illumination correction process executes the processes of:

an image generation process in which images of each registered object in the same position/pose as the target object photographed by the photographing means and under various illumination conditions are generated as illumination variation images by use of the position/pose corrected in the position/pose correction process and the data registered in the registration process; and

an illumination condition estimation process in which an image that is the most similar to the input image obtained in the photographing process is generated as the reference image by use of the illumination variation images generated in the image generation process.

[Claim 65] A record medium storing the image comparison program as claimed in claim 64, wherein:

the illumination correction process further includes an illumination variation space generation process in which an illumination variation space which is spanned by the illumination variation images generated in the image generation process is generated, and

in the illumination condition estimation process, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation process.

[Claim 66] A record medium storing the image comparison program

as claimed in claim 65, wherein:

in the illumination variation space generation process, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting principal component analysis to the illumination variation images generated in the image generation process, and

in the illumination condition estimation process, correlations are obtained between the input image obtained in the photographing process and each of the basis vectors generated in the illumination variation space generation process, and the image that is the most similar to the input image is generated as the reference image by use of the basis vectors and based on the correlations.

[Claim 67] A record medium storing the image comparison program as claimed in one of claims 64 to 66, wherein the illumination correction process further includes an illumination condition variation process in which various illumination conditions are set and generated to be used for generating illumination variation images before the illumination variation images are generated in the image generation process.

[Claim 68] A record medium storing the image comparison program as claimed in claim 60, wherein:

the registration process includes:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

a texture image photographing process in which the object to be registered is photographed under various illumination conditions and thereby texture images are obtained; and

a data storage process in which the three-dimensional shapes measured in the three-dimensional shape measurement process and the texture images obtained in the texture image photographing process are stored as the registered data, and

the illumination correction process includes:

an image generation process in which illumination variation images of each registered object in the same position/pose as the target object in the input image and under various illumination conditions are generated by use of the position/pose corrected in the position/pose correction process and the three-dimensional shapes and the texture images of the object stored in the storage process; and

an illumination condition estimation process in which an image that is the most similar to the input image obtained in the photographing process is generated as the reference image by use of the illumination variation images generated in the image generation process.

[Claim 69] A record medium storing the image comparison program as claimed in claim 68, wherein the illumination correction process further includes an illumination variation space generation process in which an illumination variation space which is spanned by the illumination variation images generated in the image generation process is generated before the reference image is generated in the illumination condition estimation process, and

in the illumination condition estimation process, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation process.

[Claim 70] A record medium storing the image comparison program as claimed in claim 69, wherein:

in the illumination variation space generation process, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting the principal component analysis to the illumination variation images generated in the image generation process, and

in the illumination condition estimation process, correlations

are obtained between the input image obtained in the photographing process and each of the basis vectors generated in the illumination variation space generation process, and the image that is the most similar to the input image is generated as the reference image by use of the basis vectors and based on the correlations.

[Claim 71] A record medium storing the image comparison program as claimed in claim 60, wherein in the position/pose correction process, the position/pose of the object is the corrected position/pose of a predetermined position/pose.

[Claim 72] A record medium storing the image comparison program as claimed in claim 60, wherein in the position/pose correction process, the position/pose is a corrected position/pose to which position/pose parameters of the object photographed by the photographing means are input.

[Claim 73] A record medium storing the image comparison program as claimed in claim 60, wherein in the position/pose correction process, the position/pose is a corrected position/pose of the estimated position/pose of the object photographed by the photographing means.

[Claim 74] A record medium storing the image comparison program as claimed in claim 73, wherein:

the registration process includes:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement process in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured;

a first feature point extraction process in which feature point positions of the registered object are extracted based on the three-dimensional shape measured in the three-dimensional shape measurement process and the reflectance measured in the reflectance

measurement process; and

a data storage process in which the three-dimensional shapes measured in the three-dimensional shape measurement process, the reflectance measured in the reflectance measurement process and the feature point positions extracted in the first feature point extraction process are stored as the registered data, and

the position/pose correction process includes:

a second feature point extraction process in which feature point positions same as those stored in the data storage process are extracted from the input image obtained in the photographing process as input image feature point positions; and

a position/pose calculation process in which the position/pose of the object photographed in the photographing means is estimated based on the three-dimensional shape and the feature point positions stored in the data storage process and the input image feature point positions obtained in the second feature point extraction process.

[Claim 75] A record medium storing the image comparison program as claimed in claim 74, wherein the illumination correction process includes:

an image generation process in which images of each object in the same position/pose as the object obtained in the photographing process and under various illumination conditions are generated as illumination variation images by use of the position/pose estimated in the position/pose determination process and the three-dimensional shape and the reflectance stored in the data storage process; and

an illumination condition estimation process in which an image that is the most similar to the input image obtained in the photographing process is generated as the reference image by use of the illumination variation images generated in the image generation process.

[Claim 76] A record medium storing the image comparison program

as claimed in claim 75, wherein:

the illumination correction process further includes an illumination variation space generation process in which an illumination variation space which is spanned by the illumination variation images generated in the image generation process is generated before the reference image is generated in the illumination condition estimation process, and

in the illumination condition estimation process, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation process.

[Claim 77] A record medium storing the image comparison program as claimed in claim 76, wherein:

in the illumination variation space generation process, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting principal component analysis to the illumination variation images generated in the image generation process, and

in the illumination condition estimation process, correlations are obtained between the input image obtained in the photographing process and each of the basis vectors generated in the illumination variation space generation process, and the image that is the most similar to the input image obtained in the photographing process is generated as the reference image by use of the basis vectors and based on the correlations.

[Claim 78] A record medium storing the image comparison program as claimed in one of claims 75 to 77, wherein the illumination correction process further includes an illumination condition variation process in which various illumination conditions are set and generated before illumination variation images are generated in the image generation

process.

[Claim 79] A record medium storing the image comparison program as claimed in claim 59, wherein:

the registration process includes:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement process in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured;

an image generation process in which images of each object to be registered under various illumination conditions are generated as illumination variation images;

an illumination variation space generation process in which an illumination variation space which is spanned by the illumination variation images generated in the image generation process is generated; and

a data storage process in which the illumination variation space generated in the illumination variation space generation process is stored as the registered data, and

the comparison process includes:

a photographing process in which the comparison target object to be compared with the registered object registered in the registration process is photographed as an input image is obtained;

an illumination condition estimation process in which an image of each object that is the most similar to the input image obtained in the photographing process is generated as a reference image from the illumination variation space stored in the data storage process;

an image comparison process in which each reference image generated in the illumination condition estimation process is compared with the input image obtained in the photographing process and thereby

an evaluation value concerning the similarity between the two images is calculated; and

a comparison judgment process in which it is judged whether or not each of the registered objects registered in the registration process is the target object photographed in the photographing process based on the evaluation value calculated in the image comparison process.

[Claim 80] A record medium storing the image comparison program as claimed in claim 59, wherein:

the registration process includes:

a three-dimensional shape measurement process for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement process for measuring the surface reflectance at each position of the three-dimensional shape of the object to be registered;

an image generation process for generating images of each object to be registered under various illumination conditions as illumination variation images;

an illumination variation space generation process for generating basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting principal component analysis to the illumination variation images generated in the image generation process; and

a data storage process for storing, as the registered data, the basis vectors generated by the illumination variation space generation process, and

the comparison process includes:

a photographing process for photographing, as an input image, the target object to be compared with the data of registered objects registered in the registration process;

an illumination condition estimation process for obtaining

correlations between the input image obtained by the photographing process and each of the basis vectors stored in the data storage process, generating, as the reference image, the image that is the most similar to the input image by use of the basis vectors and based on the correlations;

an image comparison process for comparing each reference image generated by the illumination condition estimation process with the input image obtained by the photographing process and thereby calculating an evaluation value concerning the similarity between the two images; and

a comparison judgment process for judging whether or not each of the registered objects registered in the registration process is the object photographed by the photographing process based on the evaluation value calculated by the image comparison process.

[Claim 81] A record medium storing the image comparison program as claimed in one of claims 60 to 80, wherein the three-dimensional shape measurement process measures the three-dimensional shapes by reading data or drawings.

[Claim 82] A record medium storing the image comparison program as claimed in one of claims 60 to 81, wherein the reflectance measurement process obtains the reflectance by reading data or drawings.

[Claim 83] A record medium storing the image comparison program as claimed in one of claims 60 to 82, wherein the photographing process obtains the input image by scanning a film, a photograph or printed matter.

[Claim 84] A record medium storing the image comparison program as claimed in one of claims 60 to 83, wherein the comparison judgment process judges which registered object matches the target object.

[Claim 85] A record medium storing the image comparison program as claimed in one of claims 60 to 84, wherein the comparison judgment

process searches for one or more registered objects that are similar to the target object.

[Claim 86] A record medium storing the image comparison program as claimed in one of claims 59 to 85, wherein the registered objects are automobiles.

[Claim 87] A record medium storing the image comparison program as claimed in one of claims 59 to 86, wherein the objects to be registered are human faces.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to an image comparison device and an image comparison method for comparing a target object with registered objects by use of images, and in particular, to an image comparison device and an image comparison method capable of conducting the comparison correctly withstanding variations of shooting conditions such as position/pose of the target object in the image and illumination conditions, by preliminarily registering three-dimensional shape information, surface reflectance information, color information etc. of the registered objects.

[0002]

[Prior Art]

As shown in Fig.5, image comparison techniques are such techniques that an object existing in the three-dimensional space in a random position/pose is photographed to acquire one or more input images by use of a photographing device such as camera or video camera. Thereafter, the input images of the target object are compared with images of objects which have preliminarily been registered. The image comparison process is generally composed of two steps: a registration step for registering and storing the compared objects; and a comparison

step for comparing the input image of the target object with the registered data of the registered objects and thereby judging what the target object is. In each step, the photographed image is used as a two-dimensional image without being processed, or is used after being converted to a three-dimensional shape. In the following, conventional image comparison techniques will be explained in detail with reference to documents.

[0003]

(Prior Art 1)

As an example of an image comparison technique in which two-dimensional images are registered beforehand and a two-dimensional image is used as an input image, there is disclosed a "face image comparison device" in Japanese Patent No.2872776. This prior art has been designed to conduct image comparison of human faces and has such configuration as shown in Figs. 1 and 3. In the registration step, two-dimensional images are obtained by use of a camera 11, and the obtained two-dimensional images are stored in a storage means 12. In the comparison step, a two-dimensional face image is obtained as the input image by use of a camera 13. A normalization means 14 extracts feature points being eyes, nose, etc. to be used as the criteria for judging pose, size, etc. from the input image by means of image processing. A normalized image which is normalized in accordance with two-dimensional position and size on an image is output by use of the feature points as coordinates position. Thereafter, an image comparison means 15 compares registered images reads out from the storage means 12 with the normalized image by means of pattern recognition, and outputs the result of the comparison.

[0004]

(Prior Art 2)

As an example of a conventional comparison techniques using

three-dimensional shapes, there is disclosed a "personal identification device" in Japanese Patent Application Laid-Open No.HEI9-259271. In this prior art, there is configured as shown in Fig. 14. In the registration step, a three-dimensional shape color measurement means 21 measures three-dimensional shape and color of each comparison target object, and the three-dimensional shape information and the color information are stored in a storage means 22. In the comparison step, a three-dimensional shape color measurement means 23 measures three-dimensional shape and color of a target object as input data. A translation/rotation means 24 translates the input data so that the barycenter of the input data will be on the barycenter of the registered data. Subsequently, the translation/rotation section 24 rotates the translated input data in various ways, and a minimum error calculation means 25 obtains the error between the rotated input data and the registered data. The minimum error calculation means 25 adjusts the three-dimensional position and pose of the input data. Thereafter, the minimum error calculation section 25 compares the corrected data with the registered data.

[0005]

(Prior Art 3)

A "personal identification device" disclosed in Japanese Patent Application Laid-Open No.HEI6-168317 uses two-dimensional images both in the registration step and the comparison step, and the configuration thereof is as shown in Fig. 15. In the registration step, two-dimensional images are obtained by use of a camera 41. A feature extraction means 42 extracts feature points where variations in pixel intensity are large and stores position data of the feature points in a storage means 43. In the comparison step, a two-dimensional image is obtained as an input image by use of a camera 44. Subsequently, a feature extraction section 45 extracts feature points where variations in

pixel intensity are large from the two-dimensional input image and outputs position data of the feature points. Subsequently, the comparison means 47 conducts the personal identification by comparing the registered feature point position and the feature position of the input image. Here, in order to compensate for and absorb variations in position/pose of the target object, the feature point position data output by the feature extraction means 45 is normalized by a position/pose normalization means 46 by use of a three-dimensional shape model of a standard object which has been prepared in the position/pose normalization means 46.

[0006]

(Prior Art 4)

A technique disclosed in a document: Hiroshi Murase and Shree K. Nayer "Visual Learning and Recognition of three-dimensional objects from Appearance", Int. J. Computer Vision, vol.14, pp.5-24 (1995) uses only two-dimensional images both in the registration step and the comparison step and executes correction not only for variations in position/pose but also for variations due to illumination conditions. Fig. 16 shows the configuration of the conventional art. In the registration step, a large set of sample images of each object are obtained by a photographing means 71 by automatically varying pose of the object and illumination conditions so that all feasible poses and illumination conditions can be covered. A manifold calculation means 72 obtains basis images capable of expressing the variations of the sample images, by means of principal component analysis. Subsequently, the manifold calculation section 72 generates a feature space which is spanned by the basis images, obtains a trajectory of the sample images in the feature space as a manifold, and stores the obtained manifold in a storage section 73. In the comparison step, a two-dimensional image of a target object is obtained by a camera 74 as an input image. A distance

calculation means 75 calculates the distance between the input image and the manifold in the feature space and executes the comparison using the distance as a yardstick. Thereby, the comparison by use of the input image, which can be obtained under various illumination conditions and poses, is made possible.

[0007]

(Prior Art 5)

Changes occurring to a two-dimensional image due to variations of illumination conditions when the position/pose of the object is fixed has been analyzed in detail in a document: Peter N. Belhumeur and David J. Kriegman "What is the Set of Images of an Object Under All Possible Illumination Conditions ?", Int. J. Computer Vision, vol.28, pp.245-260 (1998). In the case where the position and pose of the object are fixed, an image obtained under an arbitrary illumination condition can be resolved into images each of which is obtained under a point source of light. Therefore, an image obtained under an arbitrary number of point sources of light can be expressed as a linear combination of images each of which is obtained under a point source of light, in which the intensity of each point source is used as each coefficient of the linear combination. Based on the above analysis, a method called "illumination subspace method" which is shown in Fig. 17 has been proposed.

[0008]

Referring to Fig. 17, a photographing means 51 selects and sets three or more illumination conditions so that the number of pixels in shadow will be as small as possible, and obtains images under the three or more illumination conditions. A normal line calculation means 52 obtains reflectance vectors on the surface of the object, with regard to each pixel in the images, by means of principal component analysis. An image generation means 53 successively generates images which are

called "extreme rays" and stores the generated extreme rays in a storage means 54.

[0009]

In the comparison step, a two-dimensional image of a target object is obtained by use of a camera 55 as an input image. When the reflectance property of the surface of an object is perfect scattering and the surface is convex, an image of the object under an arbitrary illumination condition can be expressed by a linear combination of the extreme rays with positive coefficients, and therefore, an illumination correction means 56 generates a reference image being an image of the registered object under the same illumination condition as in the input image by use of a linear combination of the extreme rays. The coefficients of the linear combination are determined by use of the nonnegative least-squares method. An image comparison means 57 compares the input image with the reference image by calculating the similarity between the two images.

[0010]

(Prior Art 6)

In a technique disclosed in a document: A. S. Georghiades et al. "Illumination Cones for Recognition Under Variable Lighting: Faces", Proc. IEEE Int. Conf. CVPR, pp.52-58 (1998), when the extreme rays are obtained according to the "illumination subspace method", pixels that should be in shadow are found out based on the three-dimensional shape of the object by use of techniques of computer graphics such as ray tracing, and the pixels are shadowed. The technique of this document aims to apply the "illumination subspace method" to objects having concavities.

[0011]

(Prior Art 7)

The aforementioned document: Peter N. Belhumeur and David J.

Kriegman "What is the Set of Images of an Object Under All Possible Illumination Conditions ?", Int. J. Computer Vision, vol.28, pp.245-260 (1998), also proposes a "sampling method" which is shown in Fig. 18. It takes much time to calculate all the extreme rays as in the "illumination subspace method", and therefore, a photographing means 61 in the registration step selects and sets an appropriate number of illumination directions so that the angles (θ, ϕ) shown in Fig. 4 will cover the sphere at almost even intervals for example, and obtains images. The images obtained as above is substituted for the extreme rays. In the comparison step, the illumination correction is executed by means of the nonnegative least-squares method and thereafter the object recognition is executed.

[0012]

[Problems that the Invention is to Solve]

However, the target object in front of a photographing device being camera, video camera, etc., generally moves in the three-dimensional space (parallel translation, rotation, etc.) unless the position/pose of the target object is fixed or adjusted. Further, the illumination conditions vary every moment when the photographing of the target object is done outdoors. Therefore, the appearance of the two-dimensional input image of the target object is necessitated to vary widely. The conventional techniques could not compensate for and absorb enough the variations in the position/pose of the target object and the illumination conditions, thereby the application of the conventional image comparison techniques used to be confined within narrow limits. In the following, the problems in the conventional techniques of the above documents will be described in detail.

[0013]

The "face image comparison device" of Japanese Patent No.2872776 in accordance with the Prior Art 1 employing the simple

image comparison between two-dimensional images can not cope with variations of appearance in two-dimensional images caused by changes of the pose of the target object being three-dimensional rotation, etc., illumination conditions, etc. Therefore, the application of the technique of the document No.1 is extremely limited.

[0014]

The image comparison technique employed by the "personal identification device" of Japanese Patent Application Laid-Open No.HEI9-259271 requires three-dimensional shapes not only in the registration step but also in the comparison step. A three-dimensional shape measurement device becomes necessary on each comparison, and thus, the cost for the comparison is necessitated to be high, especially when the measurement of the target object has to be done away from the place where the registration step has performed. Further, for the measurement of the three-dimensional shape, each object has to stand still until the measurement is completed, and a darkroom etc. becomes necessary for obtaining precise data. Therefore, the application of the technique of the document No.2 is also limited.

[0015]

The technique employed by the "personal identification device" of Japanese Patent Application Laid-Open No.HEI6-168317, which detects pixel positions where variations in intensity are large, is effective for comparing objects such as blocks having large three-dimensional curvatures, black marks on a white board having steep change of reflectance, etc. However, the technique is not suitable for comparison of human faces as mentioned in the document, which means that stable and reliable detection of the feature points is difficult. The document also refers to a correction of pose by use of a standard three-dimensional shape of target objects, however, the method can not be employed unless the objects are similar in shape.

[0016]

In the technique disclosed in Hiroshi Murase and Shree K. Nayer "Visual Learning and Recognition of three-dimensional objects from Appearance", Int. J. Computer Vision, vol.14, pp.5-24 (1995), enormous amount of two-dimensional sample images have to be gathered, taking the possibilities of various illumination conditions (two or more point sources, extra lights other than point sources, etc.) into consideration. Further, the shape of the manifold in the feature space is not defined in the document at all, therefore, it is difficult to find appropriate sets of parameters when the distance between the input image and the manifold is calculated in the feature space. Therefore, large amounts of calculations are necessary for implementing the technique of the document.

[0017]

The "illumination subspace method" and the "sampling method" disclosed in Peter N. Belhumeur and David J. Kriegman "What is the Set of Images of an Object Under All Possible Illumination Conditions ?", Int. J. Computer Vision, vol.28, pp.245-260 (1998) in accordance with the Prior Arts 5 to 7 require images of the registered object illuminated from many directions. A specially designed lighting unit has to be used in the registration step, and precise setting of the illumination conditions is difficult from the viewpoints of placement and setting of equipment.

[0018]

Further, in the "illumination subspace method" and the "sampling method", if the position or pose of an object changed, images of the object in the new pose have to be obtained again under a lot of illumination conditions, and the calculations have to be done all over again. Therefore, in the registration step, a huge amount of images of the registered object in various feasible poses have to be obtained under a lot of illumination conditions, taking much time and manpower. If the

target object is photographed in the comparison step in a different pose, the comparison becomes impossible.

[0019]

Moreover, the "illumination subspace method" requires large amounts of calculation for obtaining the extreme rays, depending on the complexity of the shape. According to the document: Peter N. Belhumeur and David J. Kriegman "What is the Set of Images of an Object Under All Possible Illumination Conditions ?", Int. J. Computer Vision, vol.28, pp.245-260 (1998), when there are M independent normal vectors on the surface of the object, the number of the extreme rays amounts to M(M-1) at the maximum. Therefore, an enormous amount of extreme rays have to be calculated unless the shape of the object is very simple as a block. Therefore, it is very difficult to calculate all the extreme rays for ordinary objects having complex shapes. Further, the method can not be directly applied to cases where the object has a concavity, and thereby, a cast shadow occurs.

[0020]

In the "illumination subspace method" and the "sampling method", the amount of calculations in the nonnegative least-squares method also tends to be enormous depending on the number of extreme rays. In addition to the above problems, the sampling method also has a problem that it is not clear how many basis images are necessary for obtaining satisfactory result and performance.

[0021]

Further, the "illumination subspace method" and the "sampling method" have been constructed assuming that the surface reflectance property of each object is perfect scattering. Therefore, the methods can not be applied directly to cases where mirror reflection exists or cases where the surface reflectance property is diffusion reflection but not perfect scattering. The majority of ordinary objects do not exhibit the

surface perfect scattering.

[0022]

It is therefore the primary object of the present invention to provide an image comparison device and an image comparison method by which the comparison step can be conducted by use of a two-dimensional image of the target object obtained by use of an ordinary camera, without needing a three-dimensional shape of the target object as the input data.

[0023]

Another object of the present invention is to provide an image comparison device and an image comparison method by which the comparison of objects can be conducted correctly compensating for and absorbing the three-dimensional changes of the position/pose of the target object in the input image, necessary data of the registered objects can be gathered in the registration step easily, and the correction of illumination conditions can be conducted with regard to the input image which can be obtained under various illumination conditions at high processing speed.

[0024]

[Means of Solving the Problems]

In accordance with a first aspect of the present invention, there is provided an image comparison device comprising:

a registration means for registering data of a registration target object as three-dimensional data; and

a comparison means for obtaining, as two-dimensional data, data of an object being registered in the registration means and data of an object to be compared and comparing the data of the registered object in the registration means and obtained data.

[0025]

In accordance with a second aspect of the present invention, in the first aspect, the comparison means includes:

a photographing means for photographing, as an input image, the target object to be compared with the data of registered objects registered in the registration means;

a position/pose correction means for correcting the position/pose of the target object obtained by the photographing means;

an illumination correction means for generating, as a reference image, an image in the same position/pose as the input image, which is photographed by the photographing means, and under an illumination condition most similar to that of the input image by use of the position/pose corrected by the position/pose correction means and the data registered in the registration means;

an image comparison means for comparing the reference image generated by the illumination correction means with the input image obtained by the photographing means and thereby calculating an evaluation value concerning the similarity between the two images; and

a comparison judgment means for judging whether or not the target object photographed by the photographing means is the registered object registered in the registration means based on the evaluation value calculated by the image comparison means.

[0026]

In accordance with a third aspect of the present invention, in the second aspect, the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement means for measuring the surface reflectance at each position on the three-dimensional shape of the object to be registered; and

a data storage means for storing, as the registered data, the three-dimensional shapes measured by the three-dimensional shape measurement means and the reflectance measured by the reflectance

measurement means.

[0027]

In accordance with a fourth aspect of the present invention, in the second aspect, the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

an image information obtaining means for obtaining image information of the object by photographing the object to be registered; and

a data storage means for storing, as the registered data, the three-dimensional shapes measured by the three-dimensional shape measurement means and the image information obtained by the image information obtaining means.

[0028]

In accordance with a fifth aspect of the present invention, in the second aspect, the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

an average shape generation means for generating an average three-dimensional shape of the three-dimensional shapes measured by the three-dimensional shape measurement means when registering a plurality of objects;

a reflectance measurement means for measuring the surface reflectance at each position of the three-dimensional shape of the object to be registered; and

a data storage means for storing, as the registered data, the three-dimensional shape measured by the three-dimensional shape measurement means, the average three-dimensional shape generated by the average shape generation means and the reflectance measured by the reflectance measurement means.

[0029]

In accordance with a sixth aspect of the present invention, in one of the third to fifth aspects, the illumination correction means includes:

an image generation means for generating, as illumination variation images, images of each object in the same position/pose as the object photographed by the photographing means and under various illumination conditions by use of the position/pose corrected by the position/pose correction means and the registered data of objects in the registration means; and

an illumination condition estimation means for generating an image that is the most similar to the input image obtained by the photographing means by use of the illumination variation images generated by the image generation means and outputting the generated image to the image comparison means as the reference image.

[0030]

In accordance with a seventh aspect of the present invention, in the sixth aspect, the illumination correction means further includes an illumination variation space generation means for generating an illumination variation space which is spanned by the illumination variation images generated by the image generation means, and

the illumination condition estimation means generates the image that is the most similar to the input image from the illumination variation space generated by the illumination variation space generation means and outputs the generated image to the image comparison means as the reference image.

[0031]

In accordance with a eighth aspect of the present invention, in the seventh aspect,

the illumination variation space generation means generates

basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting principal component analysis to the illumination variation images generated by the image generation means, and

the illumination condition estimation means obtains correlations between the input image obtained by the photographing means and each of the basis vectors generated by the illumination variation space generation means, generates the image that is the most similar to the input image by use of the basis vectors and based on the correlations, and outputs the generated image to the image comparison means as the reference image.

[0032]

In accordance with a ninth aspect, in one of the sixth to eighth aspects, the illumination correction means further includes an illumination condition variation means for setting various illumination conditions and outputting the illumination conditions to the image generation means.

[0033]

In accordance with a tenth aspect of the present invention, in the second aspect,

the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each registered object;

a texture image photographing means for photographing the object to be registered under various illumination conditions and thereby obtaining texture images of the registered object; and

a data storage means for storing the three-dimensional shapes measured by the three-dimensional shape measurement means and the texture images obtained by the texture image photographing means as the registered data, and

the illumination correction means includes:

an image generation means for generating illumination variation images of each object in the same position/pose as the object photographed by the photographing means by use of the position/pose determined by the position/pose determination means and the three-dimensional shapes and the texture images of the object registered in the registration means; and

an illumination condition estimation means for generating an image that is the most similar to the input image obtained by the photographing means by use of the illumination variation images generated by the image generation means and outputting the generated image to the image comparison means as the reference image.

[0034]

In accordance with a eleventh aspect of the present invention, in the tenth aspect, wherein the illumination correction means further includes an illumination variation space generation means for generating an illumination variation space which is spanned by the illumination variation images generated by the image generation means, and

the illumination condition estimation means generates the image that is the most similar to the input image from the illumination variation space generated by the illumination variation space generation means and outputs the generated image to the image comparison means as the reference image.

[0035]

In accordance with a twelfth aspect of the present invention, in the eleventh aspect,

the illumination variation space generation means generates basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting the principal component

analysis to the illumination variation images generated by the image generation means, and

the illumination condition estimation means obtains correlations between the input image obtained by the photographing means and each of the basis vectors generated by the illumination variation space generation means, generates the image that is the most similar to the input image by use of the basis vectors and based on the correlations, and outputs the generated image to the image comparison means as the reference image.

[0036]

In accordance with a thirteenth aspect of the present invention, in the second aspect, the position/pose correction means outputs a predetermined position/pose to the illumination correction means.

[0037]

In accordance with a fourteenth aspect of the present invention, in the second aspect, the position/pose correction means receives inputs concerning position/pose parameters of the object in the input image obtained by the photographing means, and outputs the received position/pose to the illumination correction means.

[0038]

In accordance with a fifteenth aspect, in the second aspect, the position/pose correction means estimates the position/pose of the object in the input image obtained by the photographing means, and outputs the estimated position/pose to the illumination correction means.

[0039]

In accordance with a sixteenth aspect of the present invention, in the fifteenth aspect,

the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement means for measuring the surface reflectance at each position of the three-dimensional shape of the object to be registered;

a first feature point extraction means for extracting feature point positions based on the three-dimensional shape measured by the three-dimensional shape measurement means and the reflectance measured by the reflectance measurement means; and

a data storage means for storing the three-dimensional shapes measured by the three-dimensional shape measurement means, the reflectance measured by the reflectance measurement means and the feature point positions obtained by the first feature point extraction means as the registered data, and

the position/pose correction means includes:

a second feature point extraction means for extracting, from the input image obtained by the photographing means, input image feature point positions being the same feature point positions as those stored in the storage means; and

a position/pose calculation means for estimating the position/pose of the object photographed by the photographing means based on the three-dimensional shape and the feature point positions stored in the data storage means and the input image feature point positions extracted by the second feature point extraction means and outputting the estimated position/pose to the illumination correction means.

[0040]

In accordance with a seventeenth aspect of the present invention, in the sixteenth aspect, the illumination correction means includes:

an image generation means for generating images of each object in the same position/pose as the object photographed by the

photographing means and under various illumination conditions as illumination variation images by use of the position/pose estimated by the position/pose correction means and the three-dimensional shape and the reflectance stored in the data storage means; and

an illumination condition estimation means for generating an image that is the most similar to the input image obtained by the photographing means by use of the illumination variation images generated by the image generation means and outputting the generated image to the image comparison means as the reference image.

[0041]

In accordance with an eighteenth aspect of the present invention, in the seventeenth aspect,

the illumination correction means further includes an illumination variation space generation means for generating an illumination variation space which is spanned by the illumination variation images generated by the image generation means, and

the illumination condition estimation means generates the image that is the most similar to the input image from the illumination variation space generated by the illumination variation space generation means and outputs the generated image to the image comparison means as the reference image.

[0042]

In accordance with a nineteenth aspect of the present invention, in the eighteenth aspect,

the illumination variation space generation means generates basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting principal component analysis to the illumination variation images generated by the image generation means, and

the illumination condition estimation means obtains

correlations between the input image obtained by the photographing means and each of the basis vectors generated by the illumination variation space generation means, generates the image that is the most similar to the input image photographed by the photographing means by use of the basis vectors and based on the correlations, and outputs the generated image to the image comparison means as the reference image.

[0043]

In accordance with a twentieth aspect of the present invention, in one of the seventeenth to nineteenth aspects, the illumination correction means further includes an illumination condition variation means for setting various illumination conditions and outputting the illumination conditions to the image generation means.

[0044]

In accordance with a twenty-first aspect of the present invention, in the first aspect,

the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement means for measuring the surface reflectance at each position of the three-dimensional shape of the object to be registered;

an image generation means for generating images of each object to be registered under various illumination conditions as illumination variation images;

an illumination variation space generation means for generating an illumination variation space which is spanned by the illumination variation images generated by the image generation means; and

a data storage means for storing the illumination variation space generated by the illumination variation space generation means as the registered data, and

the comparison means includes:

a photographing means for photographing, as an input image, the target object to be compared with the data of registered objects registered in the registration means;

an illumination condition estimation means for generating, as a reference image, the image that is the most similar to the input image from the illumination variation space stored in the data storage means;

an image comparison means for comparing each reference image generated by the illumination condition estimation means with the input image obtained by the photographing means and thereby calculating an evaluation value concerning the similarity between the two images; and

a comparison judgment means for judging whether or not each of the registered objects registered in the registration means is the object photographed by the photographing means based on the evaluation value calculated by the image comparison means.

[0045]

In accordance with a twenty-second aspect of the present invention, in the first aspect,

the registration means includes:

a three-dimensional shape measurement means for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement means for measuring the surface reflectance at each position of the three-dimensional shape of the object to be registered;

an image generation means for generating images of each object to be registered under various illumination conditions as illumination variation images;

an illumination variation space generation means for generating basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting principal component analysis

to the illumination variation images generated by the image generation means; and

a data storage means for storing, as the registered data, the basis vectors generated by the illumination variation space generation means, and

the comparison means includes:

a photographing means for photographing, as an input image, the target object to be compared with the data of registered objects registered in the registration means;

an illumination condition estimation means for obtaining correlations between the input image obtained by the photographing means and each of the basis vectors stored in the data storage means, generating, as the reference image, the image that is the most similar to the input image by use of the basis vectors and based on the correlations;

an image comparison means for comparing each reference image generated by the illumination condition estimation means with the input image obtained by the photographing means and thereby calculating an evaluation value concerning the similarity between the two images; and

a comparison judgment means for judging whether or not each of the registered objects registered in the registration means is the object photographed by the photographing means based on the evaluation value calculated by the image comparison means.

[0046]

In accordance with a twenty-third aspect of the present invention, in one of the second to twenty-second aspects, the three-dimensional shape measurement means measures the three-dimensional shapes by reading data or drawings.

[0047]

In accordance with a twenty-fourth aspect of the present invention, in one of the second to twenty-third aspects, the reflectance

measurement means obtains the reflectance by reading data or drawings.

[0048]

In accordance with a twenty-fifth aspect of the present invention, in one of the second to twenty-fourth aspects, the photographing means obtains the input image by scanning a film, a photograph or printed matter.

[0049]

In accordance with a twenty-sixth aspect of the present invention, in one of the second to twenty-fifth aspects, the comparison judgment means judges which registered object matches the target object.

[0050]

In accordance with a twenty-seventh aspect of the present invention, in one of second to twenty-sixth aspects, the comparison judgment means searches for one or more registered objects that are similar to the target object.

[0051]

In accordance with a twenty-eighth aspect of the present invention, in one of the first to twenty-seventh aspects, the registered objects are automobiles.

[0052]

In accordance with a twenty-ninth aspect of the present invention, in one of the first to twenty-eighth aspects, the objects to be registered are human faces.

[0053]

In accordance with a thirtieth aspect of the present invention, there is provided the steps of:

a registration step in which three-dimensional data of each object to be registered are registered; and

a comparison step in which two-dimensional data of an object to be compared with the data registered in the registration step is obtained, and the obtained data is compared with the data registered in the registration step.

[0054]

In accordance with a thirty-first aspect of the present invention, in the thirtieth aspect, the comparison step includes:

a photographing step in which the comparison target object is photographed and thereby an input image is obtained;

a position/pose correction step in which the position/pose of the target object obtained in the photographing step is corrected;

an illumination correction step in which an image of each registered object in the same position/pose as the target object in the input image and under an illumination condition most similar to that of the input image is obtained as a reference image by use of the position/pose corrected in the position/pose correction step and the data registered in the registration step;

an image comparison step in which each reference image generated in the image correction step is compared with the input image obtained in the photographing step and thereby an evaluation value concerning the similarity between the two images is calculated; and

a comparison judgment step in which it is judged whether or not each registered object registered in the registration step is the object photographed in the photographing step based on the evaluation value calculated in the image comparison step.

[0055]

In accordance with a thirty-second aspect of the present invention, in the thirty-first aspect, the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement step in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured; and

a data storage step in which the three-dimensional shapes measured in the three-dimensional shape measurement step and the reflectance measured in the reflectance measurement step are stored as the registered data.

[0056]

In accordance with a thirty-third aspect of the present invention, in the thirty-first aspect, the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

a image information obtaining step in which the object to be registered is photographed and thereby image information of the object to be registered is obtained; and

a data storage step in which the three-dimensional shape measured in the three-dimensional shape measurement step and the image information obtained in the image obtaining step are stored as the registered data.

[0057]

In accordance with a thirty-fourth aspect of the present invention, in the thirty-first aspect, the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

an average shape generation step in which an average three-dimensional shape is generated as the average of a plurality of the three-dimensional shapes measured in the three-dimensional shape measurement step when registering a plurality of objects;

a reflectance measurement step in which the surface reflectance at each position of the three-dimensional shape of the object to be

registered is measured; and

a data storage step in which the three-dimensional shapes measured in the three-dimensional shape measurement step, the average three-dimensional shape generated in the average shape generation step and the reflectance measured in the reflectance measurement step are stored as the registered data.

[00058]

In accordance with a thirty-fifth aspect of the present invention, in one of the thirty-second to thirty-fourth aspects, the illumination correction step includes:

an image generation step in which images of each registered object in the same position/pose as the target object photographed by the photographing means and under various illumination conditions are generated as illumination variation images by use of the position/pose corrected in the position/pose correction step and the data registered in the registration step; and

an illumination condition estimation step in which an image that is the most similar to the input image obtained in the photographing step is generated as the reference image by use of the illumination variation images generated in the image generation step.

[0059]

In accordance with a thirty-sixth aspect of the present invention, in the thirty-fifth aspect,

the illumination correction step further includes an illumination variation space generation step in which an illumination variation space which is spanned by the illumination variation images generated in the image generation step is generated, and

in the illumination condition estimation step, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination

variation space generation step.

[0060]

In accordance with a thirty-seventh aspect of the present invention, in the thirty-sixth aspect,

in the illumination variation space generation step, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting principal component analysis to the illumination variation images generated in the image generation step, and

in the illumination condition estimation step, correlations are obtained between the input image obtained in the photographing step and each of the basis vectors generated in the illumination variation space generation step, and the image that is the most similar to the input image is generated as the reference image by use of the basis vectors and based on the correlations.

[0061]

In accordance with a thirty-eighth aspect of the present invention, in one of the thirty-fifth to thirty-seventh aspects, the illumination correction step further includes an illumination condition variation step in which various illumination conditions are set and generated to be used for generating illumination variation images before the illumination variation images are generated in the image generation step.

[0062]

In accordance with a thirty-ninth aspect of the present invention, in the thirty-first aspect,

the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

a texture image photographing step in which the object to be

registered is photographed under various illumination conditions and thereby texture images are obtained; and

a data storage step in which the three-dimensional shapes measured in the three-dimensional shape measurement step and the texture images obtained in the texture image photographing step are stored as the registered data, and

the illumination correction step includes:

an image generation step in which illumination variation images of each registered object in the same position/pose as the target object in the input image and under various illumination conditions are generated by use of the position/pose corrected in the position/pose correction step and the three-dimensional shapes and the texture images of the object stored in the storage step; and

an illumination condition estimation step in which an image that is the most similar to the input image obtained in the photographing step is generated as the reference image by use of the illumination variation images generated in the image generation step.

[0063]

In accordance with a fortieth aspect of the present invention, in the thirty-ninth aspect, the illumination correction step further includes an illumination variation space generation step in which an illumination variation space which is spanned by the illumination variation images generated in the image generation step is generated before the reference image is generated in the illumination condition estimation step, and

in the illumination condition estimation step, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation step.

[0064]

In accordance with a forty-first aspect of the present invention,

in the fortieth aspect,

in the illumination variation space generation step, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting the principal component analysis to the illumination variation images generated in the image generation step, and

in the illumination condition estimation step, correlations are obtained between the input image obtained in the photographing step and each of the basis vectors generated in the illumination variation space generation step, and the image that is the most similar to the input image is generated as the reference image by use of the basis vectors and based on the correlations.

[0065]

In accordance with a forty-second aspect of the present invention, in the thirty-first aspect, in the position/pose correction step, the position/pose of the object is the corrected position/pose of a predetermined position/pose.

[0066]

In accordance with a forty-third aspect of the present invention, in the thirty-first aspect, in the position/pose correction step, the position/pose is a corrected position/pose to which position/pose parameters of the object photographed by the photographing means are input.

[0067]

In accordance with a forty-fourth aspect of the present invention, in the thirty-first aspect, in the position/pose correction step, the position/pose is a corrected position/pose of the estimated position/pose of the object photographed by the photographing means.

[0068]

In accordance with a forty-fifth aspect of the present invention,

in the forty-fourth aspect,

the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement step in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured;

a first feature point extraction step in which feature point positions of the registered object are extracted based on the three-dimensional shape measured in the three-dimensional shape measurement step and the reflectance measured in the reflectance measurement step; and

a data storage step in which the three-dimensional shapes measured in the three-dimensional shape measurement step, the reflectance measured in the reflectance measurement step and the feature point positions extracted in the first feature point extraction step are stored as the registered data, and

the position/pose correction step includes:

a second feature point extraction step in which feature point positions same as those stored in the data storage step are extracted from the input image obtained in the photographing step as input image feature point positions; and

a position/pose calculation step in which the position/pose of the object photographed in the photographing means is estimated based on the three-dimensional shape and the feature point positions stored in the data storage step and the input image feature point positions obtained in the second feature point extraction step.

[0069]

In accordance with a forty-sixth aspect of the present invention, in the forty-fifth aspect, the illumination correction step includes:

an image generation step in which images of each object in the same position/pose as the object obtained in the photographing step and under various illumination conditions are generated as illumination variation images by use of the position/pose estimated in the position/pose determination step and the three-dimensional shape and the reflectance stored in the data storage step; and

an illumination condition estimation step in which an image that is the most similar to the input image obtained in the photographing step is generated as the reference image by use of the illumination variation images generated in the image generation step.

[0070]

In accordance with a forty-seventh aspect of the present invention, in the forty-sixth aspect, the illumination correction step further includes an illumination variation space generation step in which an illumination variation space which is spanned by the illumination variation images generated in the image generation step is generated before the reference image is generated in the illumination condition estimation step, and

in the illumination condition estimation step, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation step.

[0071]

In accordance with a forty-eighth aspect of the present invention, in the forty-seventh aspect,

in the illumination variation space generation step, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting principal component analysis to the illumination variation images generated in the image generation step, and

in the illumination condition estimation step, correlations are obtained between the input image obtained in the photographing step and each of the basis vectors generated in the illumination variation space generation step, and the image that is the most similar to the input image obtained in the photographing step is generated as the reference image by use of the basis vectors and based on the correlations.

[0072]

In accordance with a forty-ninth aspect of the present invention, in one of the forty-sixth to forty-eighth aspects, the illumination correction step further includes an illumination condition variation step in which various illumination conditions are set and generated before illumination variation images are generated in the image generation step.

[0073]

In accordance with a fiftieth aspect of the present invention, in the thirtieth aspect,

the registration step includes:

a three-dimensional shape measurement step in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement step in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured;

an image generation step in which images of each object to be registered under various illumination conditions are generated as illumination variation images;

an illumination variation space generation step in which an illumination variation space which is spanned by the illumination variation images generated in the image generation step is generated; and

a data storage step in which the illumination variation space

generated in the illumination variation space generation step is stored as the registered data, and

the comparison step includes:

a photographing step in which the comparison target object to be compared with the registered object registered in the registration step is photographed as an input image is obtained;

an illumination condition estimation step in which an image of each object that is the most similar to the input image obtained in the photographing step is generated as a reference image from the illumination variation space stored in the data storage step;

an image comparison step in which each reference image generated in the illumination condition estimation step is compared with the input image obtained in the photographing step and thereby an evaluation value concerning the similarity between the two images is calculated; and

a comparison judgment step in which it is judged whether or not each of the registered objects registered in the registration step is the target object photographed in the photographing step based on the evaluation value calculated in the image comparison step.

[0074]

In accordance with a fifty-first aspect of the present invention, in the thirtieth aspect,

the registration step includes:

a three-dimensional shape measurement step for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement step for measuring the surface reflectance at each position of the three-dimensional shape of the object to be registered;

an image generation step for generating images of each object to be registered under various illumination conditions as illumination

variation images;

an illumination variation space generation step for generating basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting principal component analysis to the illumination variation images generated in the image generation step; and

a data storage step for storing, as the registered data, the basis vectors generated by the illumination variation space generation step, and

the comparison step includes:

a photographing step for photographing, as an input image, the target object to be compared with the data of registered objects registered in the registration step;

an illumination condition estimation step for obtaining correlations between the input image obtained by the photographing step and each of the basis vectors stored in the data storage step, generating, as the reference image, the image that is the most similar to the input image by use of the basis vectors and based on the correlations;

an image comparison step for comparing each reference image generated by the illumination condition estimation step with the input image obtained by the photographing step and thereby calculating an evaluation value concerning the similarity between the two images; and

a comparison judgment step for judging whether or not each of the registered objects registered in the registration step is the object photographed by the photographing step based on the evaluation value calculated by the image comparison step.

[0075]

In accordance with a fifty-second aspect of the present invention, in one of the thirty-first to fifty-first aspects, the three-dimensional shape measurement step measures the three-dimensional shapes by

reading data or drawings.

[0076]

In accordance with a fifty-third aspect of the present invention, in one of the thirty-first to fifty-second aspects, the reflectance measurement step obtains the reflectance by reading data or drawings.

[0077]

In accordance with a fifty-fourth aspect of the present invention, in one of the thirty-first to fifty-third aspects, the photographing step obtains the input image by scanning a film, a photograph or printed matter.

[0078]

In accordance with a fifty-fifth aspect of the present invention, in one of the thirty-first to fifty-fourth aspects, the comparison judgment step judges which registered object matches the target object.

[0079]

In accordance with a fifth-sixth aspect of the present invention, in one of the thirty-first to fifty-fifth aspects, the comparison judgment step searches for one or more registered objects that are similar to the target object.

[0080]

In accordance with a fifty-seventh aspect of the present invention, in one of the thirtieth to fifty-sixth aspects, the registered objects are automobiles.

[0081]

In accordance with a fifty-eighth aspect of the present invention, in one of the thirtieth to fifty-seventh aspects, the objects to be registered are human faces.

[0082]

In accordance with a fifty-ninth aspect of the present invention, there is executing the processes of a registration process in which

three-dimensional data of each object to be registered are registered; and

a comparison process in which two-dimensional data of an object to be compared with the data registered in the registration step is obtained, and the obtained data is compared with the data registered in the registration process.

[0083]

In accordance with a sixtieth aspect of the present invention, in the fifty-ninth aspect, the comparison process executes the processes of:

a photographing process in which the comparison target object is photographed and thereby an input image is obtained;

a position/pose correction process in which the position/pose of the target object obtained in the photographing process is corrected;

an illumination correction process in which an image of each registered object in the same position/pose as the target object in the input image and under an illumination condition most similar to that of the input image is obtained as a reference image by use of the position/pose corrected in the position/pose correction process and the data registered in the registration process;

an image comparison process in which each reference image generated in the image correction process is compared with the input image obtained in the photographing process and thereby an evaluation value concerning the similarity between the two images is calculated; and

a comparison judgment process in which it is judged whether or not each registered object registered in the registration process is the object photographed in the photographing process based on the evaluation value calculated in the image comparison process.

[0084]

In accordance with a sixty-first aspect of the present invention, in the sixtieth aspect, the registration process executes the processes of:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement process in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured; and

a data storage process in which the three-dimensional shapes measured in the three-dimensional shape measurement process and the reflectance measured in the reflectance measurement process are stored as the registered data.

[0085]

In accordance with a sixty-second aspect of the present invention, in the sixtieth aspect, the registration process executes the processes of:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

a image information obtaining process in which the object to be registered is photographed and thereby image information of the object to be registered is obtained; and

a data storage process in which the three-dimensional shape measured in the three-dimensional shape measurement process and the image information obtained in the image obtaining process are stored as the registered data.

[0086]

In accordance with a sixty-third aspect of the present invention, in the sixtieth aspect, the registration process executes the processes of:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

an average shape generation process in which an average three-dimensional shape is generated as the average of a plurality of the three-dimensional shapes measured in the three-dimensional shape

measurement process when registering a plurality of objects;

a reflectance measurement process in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured; and

a data storage process in which the three-dimensional shapes measured in the three-dimensional shape measurement process, the average three-dimensional shape generated in the average shape generation process and the reflectance measured in the reflectance measurement process are stored as the registered data.

[0087]

In accordance with a sixty-fourth aspect of the present invention, in one of the sixty-first to sixty-third aspects, the illumination correction process executes the processes of:

an image generation process in which images of each registered object in the same position/pose as the target object photographed by the photographing means and under various illumination conditions are generated as illumination variation images by use of the position/pose corrected in the position/pose correction process and the data registered in the registration process; and

an illumination condition estimation process in which an image that is the most similar to the input image obtained in the photographing process is generated as the reference image by use of the illumination variation images generated in the image generation process.

[0088]

In accordance with a sixty-fifth aspect of the present invention, in the sixty-fourth aspect, the illumination correction process further includes an illumination variation space generation process in which an illumination variation space which is spanned by the illumination variation images generated in the image generation process is generated, and

in the illumination condition estimation process, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation process.

[0089]

In accordance with a sixty-sixth aspect of the present invention, in the sixty-fifth aspect, in the illumination variation space generation process, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting principal component analysis to the illumination variation images generated in the image generation process, and

in the illumination condition estimation process, correlations are obtained between the input image obtained in the photographing process and each of the basis vectors generated in the illumination variation space generation process, and the image that is the most similar to the input image is generated as the reference image by use of the basis vectors and based on the correlations.

[0090]

In accordance with a sixty-seventh aspect of the present invention, in one of the sixty-fourth to sixty-sixth aspects, the illumination correction process further includes an illumination condition variation process in which various illumination conditions are set and generated to be used for generating illumination variation images before the illumination variation images are generated in the image generation process.

[0091]

In accordance with a sixty-eighth aspect of the present invention, in the sixtieth aspect, the registration process includes:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

a texture image photographing process in which the object to be registered is photographed under various illumination conditions and thereby texture images are obtained; and

a data storage process in which the three-dimensional shapes measured in the three-dimensional shape measurement process and the texture images obtained in the texture image photographing process are stored as the registered data, and

the illumination correction process includes:

an image generation process in which illumination variation images of each registered object in the same position/pose as the target object in the input image and under various illumination conditions are generated by use of the position/pose corrected in the position/pose correction process and the three-dimensional shapes and the texture images of the object stored in the storage process; and

an illumination condition estimation process in which an image that is the most similar to the input image obtained in the photographing process is generated as the reference image by use of the illumination variation images generated in the image generation process.

[0092]

In accordance with a sixty-ninth aspect of the present invention, in the sixty-eighth aspect, the illumination correction process further includes an illumination variation space generation process in which an illumination variation space which is spanned by the illumination variation images generated in the image generation process is generated before the reference image is generated in the illumination condition estimation process, and

in the illumination condition estimation process, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation process.

[0093]

In accordance with a seventieth aspect of the present invention, in the sixty-ninth aspect, in the illumination variation space generation process, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting the principal component analysis to the illumination variation images generated in the image generation process, and

in the illumination condition estimation process, correlations are obtained between the input image obtained in the photographing process and each of the basis vectors generated in the illumination variation space generation process, and the image that is the most similar to the input image is generated as the reference image by use of the basis vectors and based on the correlations.

[0094]

In accordance with a seventy-first aspect of the present invention, in the sixtieth aspect, in the position/pose correction process, the position/pose of the object is the corrected position/pose of a predetermined position/pose.

[0095]

In accordance with a seventy-second aspect of the present invention, in the sixtieth aspect, in the position/pose correction process, the position/pose is a corrected position/pose to which position/pose parameters of the object photographed by the photographing means are input.

[0096]

In accordance with a seventy-third aspect of the present invention, in the sixtieth aspect, in the position/pose correction process, the position/pose is a corrected position/pose of the estimated position/pose of the object photographed by the photographing means.

[0097]

In accordance with a seventy-fourth aspect of the present invention, in seventy-third aspect,

the registration process includes:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement process in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured;

a first feature point extraction process in which feature point positions of the registered object are extracted based on the three-dimensional shape measured in the three-dimensional shape measurement process and the reflectance measured in the reflectance measurement process; and

a data storage process in which the three-dimensional shapes measured in the three-dimensional shape measurement process, the reflectance measured in the reflectance measurement process and the feature point positions extracted in the first feature point extraction process are stored as the registered data, and

the position/pose correction process includes:

a second feature point extraction process in which feature point positions same as those stored in the data storage process are extracted from the input image obtained in the photographing process as input image feature point positions; and

a position/pose calculation process in which the position/pose of the object photographed in the photographing means is estimated based on the three-dimensional shape and the feature point positions stored in the data storage process and the input image feature point positions obtained in the second feature point extraction process.

[0098]

In accordance with a seventy-fifth aspect of the present

invention, in the seventy-fourth aspect, the illumination correction process includes:

an image generation process in which images of each object in the same position/pose as the object obtained in the photographing process and under various illumination conditions are generated as illumination variation images by use of the position/pose estimated in the position/pose determination process and the three-dimensional shape and the reflectance stored in the data storage process; and

an illumination condition estimation process in which an image that is the most similar to the input image obtained in the photographing process is generated as the reference image by use of the illumination variation images generated in the image generation process.

[0099]

In accordance with a seventy-sixth aspect of the present invention, in the seventy-fifth aspect, the illumination correction process further includes an illumination variation space generation process in which an illumination variation space which is spanned by the illumination variation images generated in the image generation process is generated before the reference image is generated in the illumination condition estimation process, and

in the illumination condition estimation process, the image that is the most similar to the input image is generated as the reference image from the illumination variation space generated in the illumination variation space generation process.

[0100]

In accordance with a seventy-seventh aspect of the present invention, in the seventy-sixth aspect, in the illumination variation space generation process, basis vectors of a space that almost accommodates image variation due to the illumination variation are generated by conducting principal component analysis to the

illumination variation images generated in the image generation process, and

in the illumination condition estimation process, correlations are obtained between the input image obtained in the photographing process and each of the basis vectors generated in the illumination variation space generation process, and the image that is the most similar to the input image obtained in the photographing process is generated as the reference image by use of the basis vectors and based on the correlations.

[0101]

In accordance with a seventy-eighth aspect of the present invention, in one of the seventy-fifth to seventy-seventh aspects, the illumination correction process further includes an illumination condition variation process in which various illumination conditions are set and generated before illumination variation images are generated in the image generation process.

[0102]

In accordance with a seventy-ninth aspect of the present invention, in the fifty-ninth aspect,

the registration process includes:

a three-dimensional shape measurement process in which the three-dimensional shape of each object to be registered is measured;

a reflectance measurement process in which the surface reflectance at each position of the three-dimensional shape of the object to be registered is measured;

an image generation process in which images of each object to be registered under various illumination conditions are generated as illumination variation images;

an illumination variation space generation process in which an illumination variation space which is spanned by the illumination

variation images generated in the image generation process is generated; and

a data storage process in which the illumination variation space generated in the illumination variation space generation process is stored as the registered data, and

the comparison process includes:

a photographing process in which the comparison target object to be compared with the registered object registered in the registration process is photographed as an input image is obtained;

an illumination condition estimation process in which an image of each object that is the most similar to the input image obtained in the photographing process is generated as a reference image from the illumination variation space stored in the data storage process;

an image comparison process in which each reference image generated in the illumination condition estimation process is compared with the input image obtained in the photographing process and thereby an evaluation value concerning the similarity between the two images is calculated; and

a comparison judgment process in which it is judged whether or not each of the registered objects registered in the registration process is the target object photographed in the photographing process based on the evaluation value calculated in the image comparison process.

[0103]

In accordance with a eightieth aspect of the present invention, in the fifty-ninth aspect,

the registration process includes:

a three-dimensional shape measurement process for measuring the three-dimensional shape of each object to be registered;

a reflectance measurement process for measuring the surface reflectance at each position of the three-dimensional shape of the object

to be registered;

an image generation process for generating images of each object to be registered under various illumination conditions as illumination variation images;

an illumination variation space generation process for generating basis vectors of a space that almost accommodates image variation due to the illumination variation by conducting principal component analysis to the illumination variation images generated in the image generation process; and

a data storage process for storing, as the registered data, the basis vectors generated by the illumination variation space generation process, and

the comparison process includes:

a photographing process for photographing, as an input image, the target object to be compared with the data of registered objects registered in the registration process;

an illumination condition estimation process for obtaining correlations between the input image obtained by the photographing process and each of the basis vectors stored in the data storage process, generating, as the reference image, the image that is the most similar to the input image by use of the basis vectors and based on the correlations;

an image comparison process for comparing each reference image generated by the illumination condition estimation process with the input image obtained by the photographing process and thereby calculating an evaluation value concerning the similarity between the two images; and

a comparison judgment process for judging whether or not each of the registered objects registered in the registration process is the object photographed by the photographing process based on the evaluation value calculated by the image comparison process.

[0104]

In accordance with an eighty-first aspect of the present invention, in one of the sixtieth to eightieth aspects, the three-dimensional shape measurement process measures the three-dimensional shapes by reading data or drawings.

[0105]

In accordance with an eighty-second aspect of the present invention, in one of the sixtieth to eighty-first aspects, the reflectance measurement process obtains the reflectance by reading data or drawings.

[0106]

In accordance with an eighty-third aspect of the present invention, in one of the sixtieth to eighty-second aspects, the photographing process obtains the input image by scanning a film, a photograph or printed matter.

[0107]

In accordance with an eighty-fourth aspect of the present invention, in one of the sixtieth to eighty-third aspects, the comparison judgment process judges which registered object matches the target object.

[0108]

In accordance with an eighty-fifth aspect of the present invention, in one of the sixtieth to eighty-fourth aspects, the comparison judgment process searches for one or more registered objects that are similar to the target object.

[0109]

In accordance with an eighty-sixth aspect of the present invention, in one of the fifty-ninth to eighty-fifth aspects, the objects to be registered are automobiles.

[0110]

In accordance with an eighty-seventh aspect of the present invention, in one of fifty-nine to eighty-sixth aspects, the objects to be registered are human faces.

[0111]

[Embodiments of the Invention]

Referring now to the drawings, a description will be given in detail of preferred embodiments in accordance with the present invention.

[0112]

(First Embodiment)

Fig. 1 is a block diagram showing the composition and procedure of an image comparison device in accordance with a first embodiment of the present invention. Fig. 2 is a composition diagram of this embodiment. As shown in Fig. 1, a registration means 100 measures the three-dimensional shape of each object and the reflectance or color on the surface of the object by use of a three-dimensional shape measurement device, and stores both of the data. A comparison means 200 photographs a two-dimensional image by use of a video camera, etc., and compares the two-dimensional image with the data stored in the registration means 100.

[0113]

The image comparison device of the first embodiment employs the following principles that an image of an object in an arbitrary position/pose under an arbitrary illumination condition can be generated by preliminarily registering the three-dimensional shape and surface reflectance of the object, and a set of images of the object in the position/pose under various illumination conditions can be expressed as a low-dimensional subspace of the image space.

[0114]

The registration means 100 includes a three-dimensional shape

measurement means 110, a reflectance measurement means 120 and a data storage means 130.

[0115]

The three-dimensional shape measurement means 110 measures the three-dimensional shape of each object and outputs the three-dimensional shape to the data storage means 130. For example, a three-dimensional shape measurement device which has been disclosed in Japanese Patent Application No.HEI11-123687 can be employed. Other three-dimensional shape measurement devices can be employed.

[0116]

The reflectance measurement means 120 measures the reflectance of the surface of the object corresponding to the three-dimensional shape, and outputs the reflectance data to the data storage means 130. For, example, if the three-dimensional shape measurement device disclosed in Japanese Patent Application No.HEI11-123687 is employed, color information on the surface of the object can be measured simultaneously with the three-dimensional shape. Hereinafter, the color information is substituted for the reflectance data. For example, there is employed the fact that an image being photographed under such illumination conditions where the object is illuminated uniformly and any shadow is hardly cast, its intensity value is considered to be substantially in proportion to its reflectance.

[0117]

As a concrete method, a hemispherical scaffold is set up in front of the object to be registered and an appropriate number of illumination lamps are fixed to the scaffold, and an image is photographed with all lamps being turned on at the same time. Other than this method, there are various methods as to employing one or more reflectors in order to diffuse light and illuminate the object uniformly.

[0118]

The data storage means 130 stores the three-dimensional shape data and the reflectance data of each registered object. The data stored in the data storage means 130 are read out at a proper timing for the comparison process by the comparison means 200.

[0119]

The comparison means 200 includes a photographing means 210, a position/pose estimation means 220, an illumination correction means 230, an image comparison means 240 and a judgment means 250.

[0120]

The photographing means 210 which is provided with a camera, a video camera, etc. photographs a target object for correction and outputs the obtained image to the position/pose estimation means 220, the illumination correction means 230 and the image comparison means 240 as an input image.

[0121]

The position/pose estimation means 220 estimates photographing conditions such as parameters of position/pose of the object and photographing device at the time when the input image was photographed. For example, the position/pose parameters include the translation distance (Tx, Ty, Tz) of the object, rotation angles (Rx, Ry, Rz), the focal length "f" of the camera, and the viewing angle "α". The position/pose estimation means 220 is provided with an interactive interface by which the user adjusts the position/pose parameters manually watching a display.

[0122]

For example, an image of a comparison target object generated by computer graphics by use of the above 8 position/pose parameters and the input image are displayed by being superimposed on the screen. The user successively adjusts the parameters so that the two images will be in register and thereby appropriate parameters are determined. The

interactive interface is only an example and various types of devices can be employed as the position/pose estimation means 220. It is also possible to let the position/pose estimation means 220 calculate the position/pose parameters automatically.

[0123]

In the case of the automatic parameter estimation, the position/pose estimation means 220 successively generates CG images of the comparison target object in various positions/poses, compares the CG images with the input image, selects a CG image that matches the input image the best, and thereby obtains the parameters of position/pose and the photographing device, for example.

[0124]

The illumination correction means 230 generates, by use of the above parameters determined by the position/pose estimation means 220, an image, as a reference image, which is in the same position/pose as that of the input image and is under an illumination condition that is the most similar to that of the input image. In the following, the illumination correction process will be explained in detail.

[0125]

Assuming that the reflectance property on the surface of the object is perfect scattering and the surface is convex with no shadow caused by light occlusion by other parts and the light source exists at an infinite-point, the intensity value I(u, v) of each pixel (u, v) of an image can be expressed as the following [Equation 1], by use of the reflectance R(u, v) and a normal vector N(u, v) corresponding to the pixel (u, v) and the intensity Ii and a direction vector Li:

[0126]

[Equation 1]

$$I(u,v) = B(u,v)\max\left(\sum_i \left(I_i \vec{L}_i \cdot \vec{N}(u,v)\right), 0\right) \quad \cdots(1)$$

[0127]

Here, if we neglect the effect of the "max ()", an arbitrary illumination condition including cases where a plurality of lamps are used can be expressed by only one illumination vector L as follows:

[0128]

[Equation 2]

$$I(u,v) = B(u,v)\vec{N}(u,v)\cdot\vec{L}\left(\vec{L} = \sum_i l_i \vec{L}_i\right) \qquad \cdots(2)$$

[0129]

The degree of freedom of images of the object generated by the illumination variation is equal to the number of dimension of the illumination vector L, that is, 3 or less. However, the degree of freedom actually becomes higher due to the effects of the "max ()", cast shadow occurring on the surface of the object due to light occlusion by other parts, imperfect scattering on the surface, etc. However, most of the images lie in or lie sufficiently close to a three-dimensional subspace. Therefore, actually occurring image variation can be approximated as a low-dimensional subspace. The low-dimensional subspace will be hereinafter referred to as an "illumination variation space" of each object.

[0130]

The principal component analysis is used for obtaining basis vectors of the illumination variation space. A plurality of images of the target object generated by the illumination variation (hereinafter, referred to as "illumination variation images") are prepared, and a set being composed of all the images generated by the variation of illumination condition is approximated. Each of the illumination variation images is generated as an image under illumination of a single point source of light at an infinite-point. A plurality of illumination variation images are prepared by setting and changing the direction of

the point source of light at appropriate intervals so that all possible directions of the point sources in the photographing of the input image can be covered. An image obtained under plurality of illumination lamps can be expressed as the sum of images obtained under each single illumination lamp, therefore, the illumination variation images each of which is generated under a single point source of light are enough. For the generation of the illumination variation images, the three-dimensional shape data and the surface reflectance data which have been stored in the data storage means 130 are used.

[0131]

The illumination variation images can be generated by use of basic functions of computer graphics, for example. The details of the computer graphics functions have been described in a document: Mason Woo, Jackie Neider, and Tom Davis "Open GL programming Guide", Addison-Wesley Publishers Japan. In a standard function provided to computers, the reflectance property of the surface of the object is generally assumed to be perfect scattering and only shade is generated. However, in this embodiment, a reflectance model that is close to actual surface reflectance property of the object is selected and used. The mirror reflection is taken into consideration and cast shadows are also reproduced by means of ray tracing, in order to generate images that are close to reality.

[0132]

The above illumination variation image generation method by use of the CG functions of a computer is only an example. It is of course possible to generate each illumination variation image by calculating intensity of pixels that will be used for the comparison, by means of numerical calculations.

[0133]

Hereafter, each image will be expressed by use of a column

vector. Each component of the column vector indicates an intensity value of each pixel in an area of the image that will be used for the comparison. When the number of the illumination variation images is N, by expressing each illumination variation image by a vector Ki (i = 1, 2, ・・・, N), a covariance matrix V can be expressed by the following [Equation 3].

[0134]

[Equation 3]

$$S = \left[\vec{K}_1 \vec{K}_2 \cdots \vec{K}_N \right] \qquad V = \frac{1}{N} S S^T \qquad \cdots (3)$$

[0135]

Eigenvalues σi and eigenvectors Bi (i = 1, 2, ・・・M) of V are successively obtained for M largest eigenvalues starting from the largest eigenvalue, and the illumination variation space of an object "j" is approximated by an M-dimensional linear space Ψj whose bases are the eigenvectors Bi. The dimension number M of the illumination variation space may be determined in consideration of precision that is required of the illumination correction process. In the case where M eigenvectors are used, "cumulative contribution" of the M eigenvalues can be calculated by [Equation 4] as follows:

[0136]

[Equation 4]

$$\frac{\sum_{i=1}^{M} \sigma_i}{\sum_{i=1}^{N} \sigma_i} \times 100[\%] \qquad \cdots (4)$$

[0137]

The cumulative contribution is an index indicating how precisely the illumination variation space can express the illumination variation images, when error between images is evaluated by use of the differences of intensity values therebetween. By setting a threshold

value for this index, the dimension number M can be determined automatically by finding a number M necessary for surpassing the threshold value.

[0138]

Fig.3 is a block diagram showing the detailed composition and process flow of the illumination correction means 230. The illumination correction means 230 includes an illumination condition variation means 231, an image generation means 232, an illumination variation space generation means 233 and an illumination condition estimation means 234.

[0139]

The illumination condition variation means 231 sets a sufficient number of illumination conditions capable of approximating the illumination variation space of the object. For example, considering one light source at an infinite-point, and the direction of a point source of light is expressed by angles (θ, ϕ) which indicate a longitude θ and a latitude ϕ of a spherical surface of an object such as shown in Fig. 4. Each angle (θ, ϕ) is changed from -90° to 90° at intervals of 10°, and thereby, 361 types of illumination conditions are set. The type of light source, the interval or the range of illumination directions is only an example, and other settings can of course be employed.

[0140]

The image generation means 232 reads the three-dimensional shape data and the reflectance data of the object j being a comparison target from the data storage means 130, and generates the illumination variation images by use of the position/pose parameters supplied from the position/pose estimation means 220 and the illumination conditions supplied from the illumination condition variation means 231 by use of CG functions.

[0141]

The above process can be implemented by use of basic functions of a computer being provided with graphics functions. In the image generation by use of computer graphics, various types of surface reflectance models and camera models can be employed. For example, the pinhole camera model may be employed as the camera model and the perfect scattering model can be employed as the surface reflectance model. It is also possible to give shadows to the surface of the object by means of ray tracing, or to give specularity to the surface of the object by use of other reflectance models.

[0142]

In the image comparison process, reflectance property model, a light source model and a camera model are made to be close to reality, comparison quality can be improved. The image generation process can also be conducted by numerical calculations without using computer graphics.

[0143]

The illumination variation space generation means 233 calculates illumination variation space from the illumination variation images by following the [Equation 3], and outputs the obtained basis vectors to the illumination condition estimation means 234 as the illumination variation space (basis vectors) Ψj. In this embodiment, M basis vectors corresponding to the M largest eigenvalues are obtained starting from the largest eigenvalue, and the obtained M basis vectors are outputted as the illumination variation space Ψj. In order to determine the number of the basis vectors M ,for example, as the number which surpass 95% of the cumulative contribution being calculated by the [Equation 4], in the case where the number of pixels equals to or less than 361 being the number of the illumination variation images, the number of pixels is N and N eigenvalues are obtained, and a number M that satisfies the following [Equation 5] is obtained.

[0144]

[Equation 5]

$$\frac{\sum_{i=1}^{M}\sigma_i}{\sum_{i=1}^{361}\sigma_i} \geq 0.95 \qquad \cdots(5)$$

[0145]

M can be determined by applying various criterions.

[0146]

The illumination condition estimation means 234 generates, as a reference image, which is the nearest to the input image and is in the illumination variation space Ψj according to the following [Equation 6], and outputs the generated reference image to the image comparison means 240.

[0147]

[Equation 6]

$$\vec{I}_c = \sum_{i=1}^{n}\left(\vec{I}_q \cdot \vec{B}_i\right)\vec{B}_i \qquad \cdots(6)$$

[0148]

The image comparison means 240 calculates an evaluation value concerning the similarity between the input image and the generated reference image. Various calculation methods can be employed for the evaluation. For example, the sum of squares of difference of intensity value of each pixel of an image which is shown in the following equation (7) can be used as the evaluation value.

[0149]

[Equation 7]

$$D = \left|\vec{I}_q - \vec{I}_c\right|^2 \qquad \cdots(7)$$

[0150]

A technique elaborated on in a document: Shigeru Akamatsu "Computer Recognition of Human Faces - A Survey -", The Transactions

of the Institute of Electronics, Information and Communication Engineers D-II, Vol.J-80-D-II, No.8, pp.2131-2146 (1997), can also employed.

[0151]

The judgment means 250 judges whether or not the comparison target image is the registered image by processing the calculated evaluation value as a threshold value.

[0152]

Comparison processing of an object may be performed by use of the distance of illumination variation space between a input image vector Iq and a comparison target object as a measure. This distance exists in the illumination variation space Ψj, and is calculable as the distance between the input image and an image vector Ic being closest to the input image. While various measures can be used as a measure of a distance, a description will be given of an example in which a square error of intensity value is directly used, here.

[0153]

In the case where this distant measure is used, the image vector Ic being closest to the vector Iq in the space Ψj can be generated by the [Equation 6]

[0154]

A distance D (a sum of square of intensity value) between a reference image vector Ic and the input image vector Iq can be calculated by the [Equation 7].

[0155]

The value D is an evaluation value of similarity between the input image and the registered data, and based on this evaluation value, judgment processes such as whether or not the target image is the registered image, to which registered images the input image corresponds, to which registered image the input image is similar, are

performed. For example, for simply judging whether or not the target image is the registered image, a threshold value D' is predetermined, and the target object is judged to be the registered object if $D < D'$.

[0156]

When a plurality of objects have been registered, the process from the reference image generation by the illumination correction means 230 to the evaluation value calculation by the image comparison means 240 are repeated for a plural times. In this case, the judgment means 250 can judge which registered object is the most similar to the target object. It is also possible to search for one or more registered objects having more than certain evaluation values as objects similar to the target object.

[0157]

(Second Embodiment)

Next, a detailed description will be given of a second embodiment of the present invention with reference to Figs. 6 and 7. Fig. 6 is a block diagram showing the composition and operation of an image comparison device in accordance with the second embodiment of the present invention. This embodiment differs from the first embodiment in that by photographing images under a plurality of illumination conditions, and by use of the images instead of the reflectance, illumination variations images are generated, instead of measuring the reflectance by use of the reflectance measurement means 120 in the first embodiment. Further, in the second embodiment, the illumination condition variation means is not provided.

[0158]

In the second embodiment, there is set an adequate number of illumination conditions for generating enough sample images for generating illumination variation spaces including the variation of the image of the comparison target object due to the illumination conditions.

By photographing image information under the illumination conditions, it is possible to generate sample images for generating illumination variation space without the need of the reflectance measurement, illumination condition setting in the CG image generation, shadow generation by means of ray tracing, etc.

[0159]

As an example of a method which can be applied to a photographing process of texture images to be used for the sample images, there is the following method. A hemispherical scaffold is set up in front of the object to be registered and an appropriate number of illumination lamps are fixed to the scaffold at even intervals. The object is photographed repeatedly by successively turning each lamp on. It is also possible to photograph the object repeatedly moving a lamp by a manipulator and turning the lamp on repeatedly.

[0160]

In the second embodiment, the photographed texture images are registered and stored together with the three-dimensional shape data as the registered data. The comparison step is conducted without executing the illumination condition variation process. Instead of the illumination condition variation process, the stored texture images are successively read out and an image of the registered object in the position/pose estimated by the position/pose estimation process is generated by means of computer graphics so that intensity values on the surface of the object in the generated image will be the same as those of the texture images. The generated image is output as the sample image. The second embodiment will hereafter be explained in detail.

[0161]

In a registration means 2100, as registration data to be used for comparison of the object, the three-dimensional shape of each object and image data (texture images) of each object obtained under a plurality of

illumination conditions are registered. The registration means 2100 includes a three-dimensional shape measurement means 2110, a texture image photographing means 2120 and a data storage means 21390.

[0162]

The three-dimensional shape measurement means 2110 measures the three-dimensional shape of each object by use of a three-dimensional shape measurement device such as the device disclosed in Japanese Patent Application No.HEI11-123687, and outputs the three-dimensional shape data to the data storage means 2130.

[0163]

The texture image photographing means 2120 actually sets illumination conditions which are equivalent to those set and output by the illumination condition variation means 231 of the first embodiment, and photographs each object under the illumination conditions. For example, a hemispherical scaffold is set up in front of the registered object and an appropriate number of illumination lamps are fixed to the scaffold. Concretely, in the angles (θ, ϕ) shown in Fig. 4 with respect to the object, the lamps are fixed to points corresponding to angles from -90° to 90° at intervals of 15° for example, and the object is photographed repeatedly by successively turning each lamp on. It is also possible to photograph the registered object repeatedly moving a lamp by a manipulator and turning the lamp on repeatedly. The texture images obtained above are output to the data storage means 2130.

[0164]

The data storage means 2130 stores the three-dimensional shape data of the objects supplied from the three-dimensional shape measurement means 2110 and the texture images supplied from the texture image photographing means 2120. The registered data are read out at the time of the comparison process by the comparison means 2200.

[0165]

The comparison means 2200 includes a photographing means 2210, a position/pose estimation means 2220, an illumination correction means 2230, an image comparison means 2240 and a judgment means 2250.

[0166]

The photographing means 2210 which is provided with a camera, a video camera, etc. photographs a comparison target object and outputs the obtained image to the position/pose estimation means 2220, the illumination correction means 2230 and the image comparison means 2240 as an input image.

[0167]

The position/pose estimation means 2220 estimates position/pose parameters, photographing device parameters, etc. at the time when the target object was photographed. The position/pose parameters include translation distance (Tx, Ty, Tz) of the object, rotation angles (Rx, Ry, Rz) of the object, the focal length "f" of the camera, and the viewing angle "α" of the camera, for example. The position/pose estimation means 2220 is provided with an interactive interface, and the user of the position/pose estimation means 2220 adjusts the position/pose parameters manually watching a display screen.

[0168]

The illumination correction means 2200 does not include the illumination condition variation means 231, and therefore, in the image generation means 2232, illumination variation images are generated by use of, as intensity value of a surface of the object, the texture images being photographed by the texture image photographing means 2120.

[0169]

Fig. 7 is a block diagram showing the composition and process flow of an illumination correction means 2230 according to the second

embodiment. The illumination correction means 2230 includes an image generation means 2232, an illumination variation space generation means 2233 and an illumination condition estimation means 2234.

[0170]

The image generation means 2232 reads out the three-dimensional shape data and the texture images of a comparison target object "j" from the data storage means 2130, and generates illumination variation images by computer graphics, by use of the position/pose parameters obtained by the position/pose estimation means 2220 and each of the texture images. The process can be conducted by means of texture mapping, which is a basic function of a computer having graphic functions. In the second embodiment, various types of camera models such as the pinhole camera model can be employed. The texture images employed in the second embodiment are actually photographed images, therefore, there is no need to generate shadows and specularity by computer graphics as in the first embodiment.

[0171]

The illumination variation space generation means 2233 calculates illumination variation space by use of the illumination variation images generated by the image generation means 2232 according to the [Equation 3], and the calculated basis vectors are output to the illumination condition estimation means 2234 as the illumination variation space (basis vectors) Ψj.

[0172]

The illumination condition estimation means 2234 generates, as a reference image, an image which is the nearest in the illumination variation space Ψj to the input image by use of the input image according to the [Equation 6], and the generated reference image is output to the image comparison means 2240.

[0173]

The image comparison means 2240 calculates an evaluation value concerning the similarity between the input image and the generated reference image.

[0174]

The judgment means 2250 judges whether or not the target image is the registered image by use of the calculated evaluation value and a threshold value. When a plurality of objects have been registered, the reference image generation by the illumination correction means 2230 and the evaluation value calculation by the image comparison means 2240 are conducted repeatedly. In this case, the judgment means 2250 can judge which registered object is the most similar to the target object. It is also possible to search for one or more registered objects that are similar to the target object by finding registered objects having more than certain evaluation value.

[0175]

According to the second embodiment of the present invention, more time and effort become necessary in the data registration step in comparison with the first embodiment since the texture images have to be obtained by actually photographing objects to be registered to the data storage means 2130. However, numerical calculations for the approximation in the low-dimensional space and the processes for generating shadows and specularity can be omitted since the actually photographed texture images are used for the illumination correction process, and therefore, processing time necessary for the comparison step can be shortened in comparison with the first embodiment.

[0176]

(Third Embodiment)

In the following, a detailed description will be given of a third embodiment of the present invention. Fig. 8 is a block diagram showing

the composition and process flow of an image comparison device in accordance with the third embodiment of the present invention. In this embodiment, instead of the three-dimensional shape measurement means 3110 which measures the three-dimensional shapes of all objects when registering a plurality of objects in the first embodiment, by measuring the three-dimensional shapes of one or a small number of objects, an average shape generation means 3150 generates an average three-dimensional shape of the measured objects. The third embodiment is different from the first embodiment in that shapes of all the comparison target objects are not measured, and that a comparison means 3200 uses the three-dimensional shape of the average shape.

[0177]

The image comparison device of the third embodiment can perform the position/pose estimation process and the illumination correction process by use of the representative three-dimensional shape data instead of measuring and using the three-dimensional shapes of all objects in the case where the shapes of the objects are similar.

[0178]

A registration means 3100 includes a three-dimensional shape measurement means 3110, an average shape generation means 3150, a reflectance measurement means 3120 and a data storage means 3130.

[0179]

The three-dimensional shape measurement means 3110 measures three-dimensional shapes of objects 1 and 2, by use of such a three-dimensional shape measurement device as disclosed in Japanese Patent Application No.HEI11-123687.

[0180]

The average shape generation means 3150 translates the three-dimensional shape data of the registered object 1 or 2 so that the barycenters of the objects 1 and 2 will overlap one another as shown in

Fig. 9(a), sets sections that are perpendicular to the z-axis at appropriate intervals, and calculates average shapes on each of the sections. As shown in Fig. 9(b), a line being average calculation line is drawn outward from the barycenter of the object on the section, and intersection points P_1 and P_2 of the average calculation line with shapes of the objects 1 and 2 are obtained. The three-dimensional coordinates of a point P_m of the average shape are obtained by averaging three-dimensional coordinates (x_1, y_1, z_1) and (x_2, y_2, z_2) of the surface points P_1 and P_2 as expressed by [Equation 8]:

[0181]

[Equation 8]

$$\left(\frac{x_1+x_2}{2}, \frac{y_1+y_2}{2}, \frac{z_1+z_2}{2}\right) \qquad \cdots(8)$$

[0182]

By performing the above process by repeating the above calculation around the barycenter at proper intervals, the average shape of the objects 1 and 2 can be generated. Thereby, the generated average shape can be output to the data storage means 3130.

[0183]

The reflectance measurement means 3120 measures the reflectance of the surface of each object 1 and 2 corresponding to the three-dimensional shape. If the three-dimensional shape measurement device of Japanese Patent Application No.HEI11-123687 is employed, color information on the surface of the object can be measured simultaneously with the three-dimensional shape. In the following, the color information is substituted for the reflectance data. The correspondence between each point of the average three-dimensional shape and the color information of each registered object can be set as follows. That is, if we express the three-dimensional shape data of the objects 1 and 2 which have been used for the calculation of the

three-dimensional coordinates of the average three-dimensional shape P_m as P_1 and P_2, reflectance data of the object 1 corresponding to the P_m is the reflectance corresponding to the P_1, and in the same way, reflectance data of the object 2 corresponding to the average shape P_m is the reflectance corresponding to P_2.

[0184]

The data storage means 3130 stores the average shape data input from the three-dimensional shape measurement means 3110 and the reflectance of the objects 1 and 2 input from the reflectance measurement means 3120.

[0185]

The processing of the comparison means 3200 is basically the same as that of the comparison means 200 of the first embodiment, except that the average three-dimensional shape data read out from the data storage means 3130 is changed to the average shape of each of objects 1 and 2.

[0186]

While an embodiment in which an average shape of two objects is stored when two objects are registered has been explained above, this embodiment is only for an example. An embodiment in which the number of objects is more than three and arbitrary number thereof are calculated for obtaining the average shape is also possible by the same processing.

[0187]

(Fourth Embodiment)

In the following, a detailed description will be given of a fourth embodiment of the present invention. In the fourth embodiment, human face is used as an example of a comparison target object. Fig. 10 is a block diagram showing the composition and process flow of an image comparison device in accordance with this embodiment. Differently

from the image comparison device of the first embodiment, a registration means 4100 is further provided with a feature point extraction means 4140 which extracts feature points where intensity etc. changes steeply from each object and outputs the extracted points as the feature point positions. A data storage means 4130 of the fourth embodiment also stores the feature point positions. In a comparison means 4200 of the fourth embodiment, a position/pose estimation means 4220 reads out the feature point positions from the data storage means 4130 and automatically executes the position/pose estimation.

[0188]

According to this embodiment, if feature point positions of the comparison target object in the input image can be extracted and three-dimensional coordinates of the feature points can be obtained based on the registered data, parameters concerning the position/pose of the object in the input image and parameters concerning the photographing device can be obtained automatically by use of the positions of the feature points on the input image and the three-dimensional coordinates. As a method for automatically obtaining the parameters concerning the position/pose and the photographing device when positions of points in an image and three-dimensional coordinates of the points are known, a camera calibration method can be used.

[0189]

In short, it is a method that, instead of comparing images, the position of the points or areas having features (hereinafter referred to as feature points) where intensity changes steeply etc. on an image is detected in the input image and CG images, and thereby, parameters concerning the position/pose and the photographing device are calculated by selecting a CG image whose feature point positions are the nearest to those of the input image.

[0190]

It is also possible to determine the position/pose of the target object by use of the relationship between the feature point positions in the input image. In a document: Shinn-Ying Ho and Hui-Ling Huang "An analytic solution for the pose determination of human faces from a monocular image", Pattern Recognition Letters, Vol.19, pp.1045-1054 (1998), feature points such as the tails of eyes and the ends of lips are used when human faces are used as a comparison target object, and the position/pose of an object is determined by use of the relationship between the feature points such that a line connecting two eye-feature points is parallel to a line connecting two mouth-feature points, etc. Hereinafter, a detailed description will be given of this embodiment.

[0191]

The registration means 4100 includes a three-dimensional shape measurement means 4110, a reflectance measurement means 4120, a feature point extraction means 4140 and a data storage means 4130. In the registration means 4100, the three-dimensional shape and reflectance of each object are measured as the registered data to be used for the object comparison, and three-dimensional coordinates of feature points of the object are obtained by use of the measured three-dimensional shape and reflectance. The three-dimensional shape, the reflectance or color information and the feature point positions are registered.

[0192]

The three-dimensional shape measurement means 4110, which is provided with a three-dimensional shape measurement device, measures the three-dimensional shape of each object. While the three-dimensional shape measurement device of Japanese Patent Application No.HEI11-123687 is employed in the fourth embodiment as an example, other devices can of course be used.

[0193]

The reflectance measurement means 4120 measures the reflectance of the surface of the object corresponding to the three-dimensional shape. If the three-dimensional shape measurement device of Japanese Patent Application No.HEI11-123687 is employed, color information on the surface of the object can be measured simultaneously with the three-dimensional shape. The color information obtained by the device will hereafter be substituted for the reflectance.

[0194]

The feature point extraction means 4140 detects points or areas where intensity etc. changes steeply (hereinafter referred to as feature points) of the object on an image, and outputs the three-dimensional coordinates of the feature points (feature point positions) in the data storage means 4130. For example, when human faces are comparison target objects, parts where reflectance changes steeply such as tails of eyes, lips, etc., parts where the three-dimensional shape changes steeply such as tip of nose etc., are detected. The feature point detection process can be conducted by manual operation. For the automatic feature point extraction process, various methods including those disclosed in the aforementioned Japanese Patent No.2872776: "face image comparison device" and the aforementioned Japanese Patent Application Laid-Open No.HEI6-168317: "personal identification device" can be employed. In this embodiment, twelve points (0 ～ 11) shown in Fig.12 are used as the feature points. The definition of the feature points can of course be altered depending on what the comparison target object is. In the following explanation, the feature point positions being three-dimensional coordinates will be expressed by use of vectors $Ai = (x_i, y_i, z_i)$ $(i = 0, 1, \cdots, 11)$.

[0195]

The data storage means 4130 stores the three-dimensional shapes, the reflectance and the feature point positions of the registered objects. The registered data is read out when the comparison step is conducted by the comparison means 4200.

[0196]

The comparison means 4200 includes a photographing means 4210, a position/pose estimation means 4220, an illumination correction means 4230, an image comparison means 4240 and a judgment means 4250.

[0197]

The photographing means 4210, which is provided with a camera, a video camera, etc., photographs the comparison target object and thereby obtains the input image. The input image obtained by the photographing means 4210 is supplied to the position/pose estimation means 4220, the illumination correction means 4230 and the image comparison means 4240.

[0198]

The position/pose estimation means 4220 estimates the parameters concerning the position/pose of the object and parameters concerning the photographing device being the condition at the time when the target object was photographed. Fig. 11 is a block diagram showing the composition and process flow of the position/pose estimation means 4220. The position/pose estimation means 4220 includes an input image feature point extraction means 4221 and a position/pose calculation means 4222.

[0199]

The input image feature point extraction means 4221 extracts, from the input image, feature points being the same position as feature point vectors A_i extracted by the feature point extraction means 4140 of the registration means 4100, and outputs position vectors on the image

$Bi = (u_i, v_i)$ ($i = 0, 1, \cdots, 11$) to the position/pose calculation means 4222 as input image feature point positions. The input image feature point extraction process can be conducted by manual operation of an operator seeing the input image on the screen. The methods employed by the feature point extraction means 4140 such as the methods disclosed in the aforementioned Japanese Patent Application Laid-Open No.HEI6-168317: "personal identification device" can be used.

[0200]

While human face comparison is taken as an example in this embodiment, the image comparison device of the fourth embodiment can be used for the comparison of polyhedron-like objects, for example, by using apexes of the objects as the feature points. Edges are extracted from each object in the image, and the apexes of the object are detected as intersection points of the edges. When some characteristic patterns exist on the surfaces of the objects, the positions of the patterns can be used.

[0201]

The position/pose calculation means 4222 calculates parameters concerning the position/pose of the target object in the input image and parameters concerning the photographing device by use of the feature point positions read out from the data storage means 4130 and the input image feature point positions input by the input image feature point extraction means 4221, and outputs the calculated parameters to the illumination correction means 4230 as the position/pose. For this calculation various methods, including a method disclosed in a document: Roger Y. Tsai "An Efficient and Accurate Camera Calibration Technique for 3D Machine Vision", Proc. CVPR '86, pp364-374 (1986), can be employed.

[0202]

In this embodiment, the position/pose parameters employed in

the fourth embodiment include, for example, the translation distance (Tx, Ty, Tz) of the object, rotation angles (Rx, Ry, Rz) of the object around the x-axis, y-axis and z-axis and the focal length "f" of the camera. The pinhole camera model is employed as the camera model. The relationship between the feature point position vector Ai and the input image feature point position vector Bi can be expressed by the following [Equation 9].

[0203]

[Equation 9]

$$\begin{bmatrix} u_i \\ v_i \end{bmatrix} = \frac{f}{c} \begin{bmatrix} a \\ b \end{bmatrix} \quad \cdots (9)$$

[0204]

where "a", "b" and "c" are defined as following [Equation 10]:

[0205]

[Equation 10]

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = R \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} \quad \cdots (10)$$

[0206]

where "R" is the following rotation matrix expressed by the [Equation 11]:

[0207]

[Equation 11]

$$R = \begin{bmatrix} \cos R_y \cos R_z & -\cos R_x \sin R_z + \sin R_x \sin R_y \cos R_z & \sin R_z \sin R_x + \cos R_x \sin R_y \cos R_z \\ \cos R_y \sin R_z & \cos R_x \cos R_z + \sin R_x \sin R_y \sin R_z & -\sin R_x \cos R_z + \cos R_x \sin R_y \sin R_z \\ -\sin R_y & \sin R_x \cos R_y & \cos R_x \cos R_y \end{bmatrix} \quad \cdots (11)$$

[0208]

The position/pose parameters Rx, Ry, Rz, Tx, Ty, Tz, f by

optimization calculation so that the sum of the differences between the value obtained by the [Equation 9] and the input image feature point positions with respect to the 12 feature points will be the smallest. The optimization calculation can be executed in various ways. The obtained Rx, Ry, Rz, Tx, Ty, Tz, f are supplied to the illumination correction means 4230 as position/pose parameters. The definitions of the position/pose parameters and the camera model and the calculation method explained above are only examples, and thus, the position/pose calculation process can be conducted according to various methods.

[0209]

The illumination correction means 4230 generates an image, as a reference image, of an object in the same position/pose as an object in the input image under an illumination condition that is the most similar to that of the input image, using the parameters obtained by the position/pose estimation means 4220.

[0210]

The image comparison means 4240 calculates an evaluation value concerning the similarity between the input image and the generated reference image. Various calculation methods can be employed for the evaluation. For example, the sum of squares of pixel intensity differences which has been shown in the [Equation 7] can be used as the evaluation value.

[0211]

The judgment means 4250 executes judgment whether or not the comparison target image is the registered image by use of the calculated evaluation value and a threshold value. When a plurality of objects have been registered as the registered objects, the reference image generation by the illumination correction means 4230 and the evaluation value calculation by the image comparison means 4240 are conducted repeatedly for each registered object. It is also possible to

search for one or more registered objects that are similar to the target object by finding registered objects giving certain evaluation values.

[0212]

(Fifth Embodiment)

In the following, a detailed description will be given of an image comparison device in accordance with a fifth embodiment of the present invention. In this embodiment, the objects to be registered are industry products etc. whose design drawings of the shapes have been saved as CAD data and whose surface painting specifications etc. have been designated and written in drawings. Differently from the first embodiment, a three-dimensional shape measurement means 110 of the fifth embodiment obtains the three-dimensional shape data from the CAD data of design drawings, and a reflectance measurement means 120 of the fifth embodiment obtains the reflectance data by reading drawings. The image comparison device of the fifth embodiment can preferably be applied to cases where the three-dimensional shape measurement by use of an ordinary three-dimensional shape measurement device is difficult (for example, when the registered objects are houses, buildings, etc.) and the three-dimensional shape is obtained by actually making a survey or measurement.

[0213]

The three-dimensional shape measurement means 110 reads the CAD data of the of the design drawings, converts the CAD data into a data format that can be handled by the comparison means 200, and outputs the converted data to the data storage means 130.

[0214]

The reflectance measurement means 120 reads data concerning the colors, surface finishing conditions, etc. of parts of the objects from the design drawings, converts the data into reflectance data, and outputs the data to the data storage means 130.

[0215]

The data storage means 130 stores the three-dimensional shape data obtained by the three-dimensional shape measurement means 110 and the reflectance data obtained by the reflectance measurement means 120.

[0216]

The comparison means 200 of the fifth embodiment conducts the comparison step in the same way as the first embodiment.

[0217]

As described in the above embodiment, the present invention can be applied to general objects. Especially, the present invention can be applied to the comparison of the type and form of automobiles, and also the comparison of human faces.

[0218]

As set forth hereinabove, while a detailed description has been given of the embodiments of the present invention with reference to the drawings, it is not to be restricted by those embodiments, and change or modification of the embodiment is to be appreciated without departing from the subject matter of the present invention. The present invention can also be implemented by use of a computer program.

[0219]

[Effect of the Invention]

According to the present invention, as it is clear from the above explanation, three-dimensional shapes of objects and reflectance of surface of the objects or images under appropriate conditions of illumination are measured only by the registration means, and photographing device such as video camera for photographing general two-dimensional images is enough as a photographing means in a comparison means, and thereby, a practical device can be constructed without a need of a three-dimensional shape measurement device in the

comparison step.

[0220]

Further, three-dimensional shapes are registered, and therefore, perfect correction is possible with respect to the change of the three-dimensional position/pose in the input images. The present invention can be applied to the target objects whose surface reflectance properties are not perfect scattering, and also applied to the target objects which cast shadows due to light occlusion by other parts, specularity, etc. occurring on the surfaces, and therefore, enough correction can be executed with respect to the variation of illumination conditions. Thus, the present invention can be applied to comparison of general objects in wider range than the above Illumination Subspace Method, or the Sampling Method.

[0221]

Moreover, in the comparison step, illumination variation images can automatically be generated by use of registered three-dimensional shapes and reflectance, and accordingly, the registration step can be performed easily since photographing a lot of images is not needed. Furthermore, by use of the cumulative contribution, an enough dimension number of subspace as an approximation of the illumination variation space can be obtained, and therefore, the amount of calculations necessary for the illumination correction process can be reduced without deteriorating the accuracy of the image comparison.

[Brief Description of the Drawings]

[Fig. 1]

A block diagram showing the composition and process flow of an image comparison process in accordance with a first embodiment of the present invention.

[Fig. 2]

A constitutive diagram in accordance with the first embodiment

of the present invention.

[Fig. 3]

A block diagram showing the composition and process flow of an illumination correction means 230 in accordance with the first embodiment.

[Fig. 4]

A diagram for explaining angles indicating the direction of illuminations which are used for the setting of illumination conditions with respect to an object.

[Fig. 5]

A diagram showing an example of an object comparison device using images.

[Fig. 6]

A block diagram showing the composition and process flow of an image comparison device in accordance with a second embodiment of the present invention.

[Fig. 7]

A block diagram showing the composition and process flow of an illumination correction means 2230 in accordance with the second embodiment of the present invention.

[Fig. 8]

A block diagram showing the composition and process flow of an image comparison device in accordance with a third embodiment of the present invention.

[Fig. 9]

Diagrams for explaining a generation method of an average shape.

[Fig. 10]

A block diagram showing the composition and process flow of an image comparison device in accordance with a fourth embodiment of the

present invention.

[Fig. 11]

A block diagram showing the composition and process flow of a position/pose estimation means 4220 in accordance with the fourth embodiment of the present invention.

[Fig. 12]

A diagram showing an example of points employed as feature points of a target object.

[Fig. 13]

A block diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which only two-dimensional images are employed in both the registration step and the comparison step.

[Fig. 14]

A block diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which three-dimensional shapes are measured in both the registration step and the comparison step.

[Fig. 15]

A block diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which two-dimensional images are employed in both the registration step and the comparison step, and standard three-dimension shape is employed in the position/pose correction step.

[Fig. 16]

A block diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which images are photographed under a lot of position/pose conditions in the registration step and recognition is performed.

[Fig. 17]

A block diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which two-dimensional images are photographed under a plurality of illumination conditions in the registration step, and illumination condition correction is performed.

[Fig. 18]

A schematic block diagram for explaining, as an example of a conventional image comparison technique, the composition of a technique in which two-dimensional images are photographed under a plurality of illumination conditions in the registration step, and illumination condition correction is performed.

[Description of Codes]

100 Registration means
110 Three-dimentional shape measurement means
120 Reflectance measurement means
130 Data storage means
200 Comparison means
210 Photographing means
220 Position/pose estimation means
230 Illumination correction means
231 Illumination condition variation means
232 Image generation means
233 Illumination variation space generation means
234 Illumination condition estimation means
240 Image comparison means
250 Judgment means

[Title of Document] Abstract

[Abstract]

[Problem] To provide an image comparison device, an image comparison method and a memory medium in which a program thereof is stored, where three-dimension shapes are not needed to be measured in a comparison step, and identification of whether or not a target object is a registered object, comparison of which registered object is the target object, and a search of similar objects are performed by use of images photographed with various position/pose of objects and under various illumination conditions.

[Means of Solving] A registration means 100 measures the three-dimensional shape and surface reflectance of an object to be registered and stores them as registered data. In a comparison means 200, a photographing means 210 photographs an input image. A position/pose estimation means 220 estimates the position/pose of the object in the input image by use of the registered three-dimension shape and reflectance. An illumination correction means 230 generates, as a reference image, an image of the object in the same position/pose as the object in the input image and under the same illumination condition as in the input image by use of the registered three-dimensional shape and reflectance. An image comparison means 240 calculates an evaluation value concerning the similarity between the reference image and the input image. A judgment means 250 performs comparison judgment based on the evaluation value.

[Selected Drawing] Fig. 1

FIG. 1

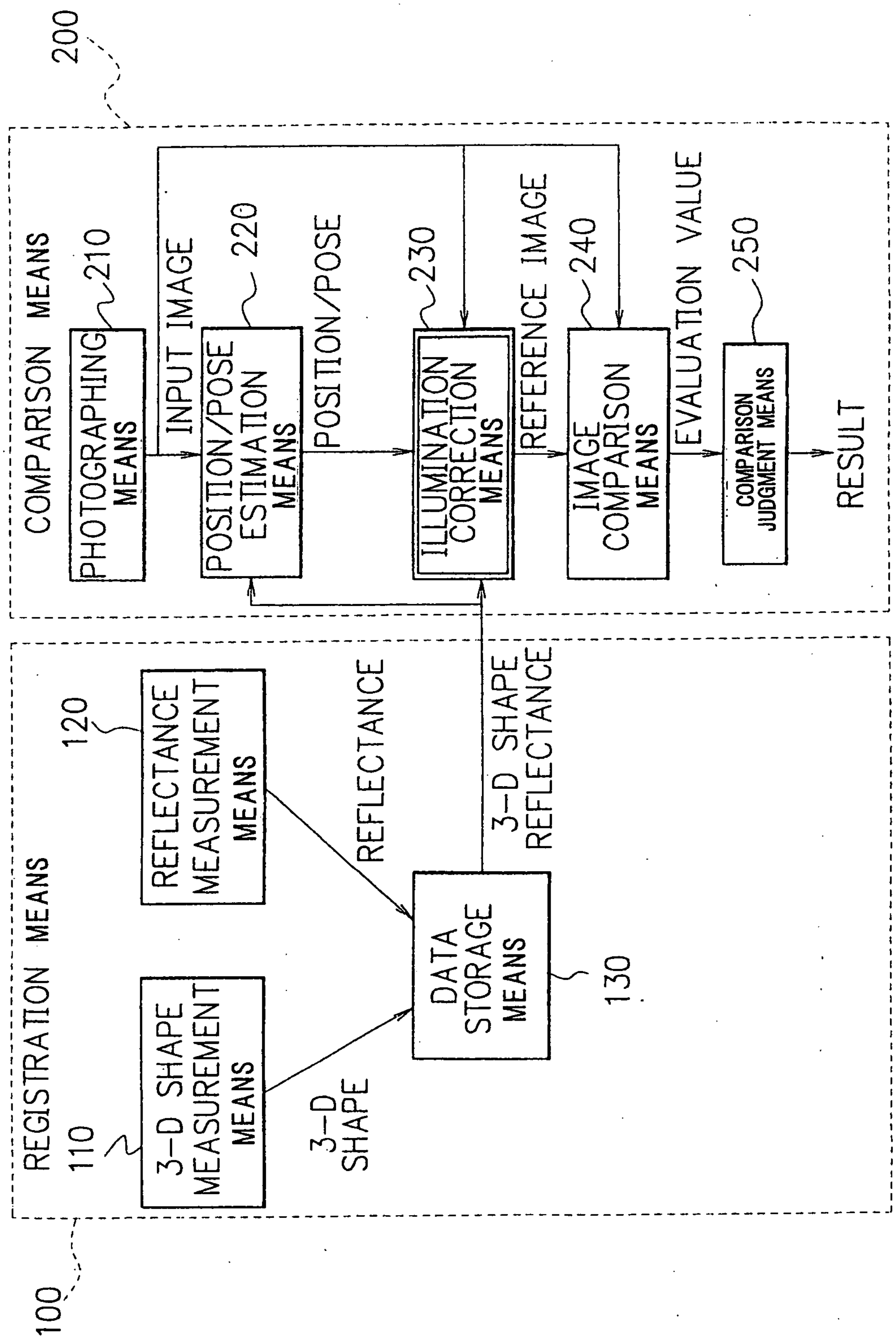
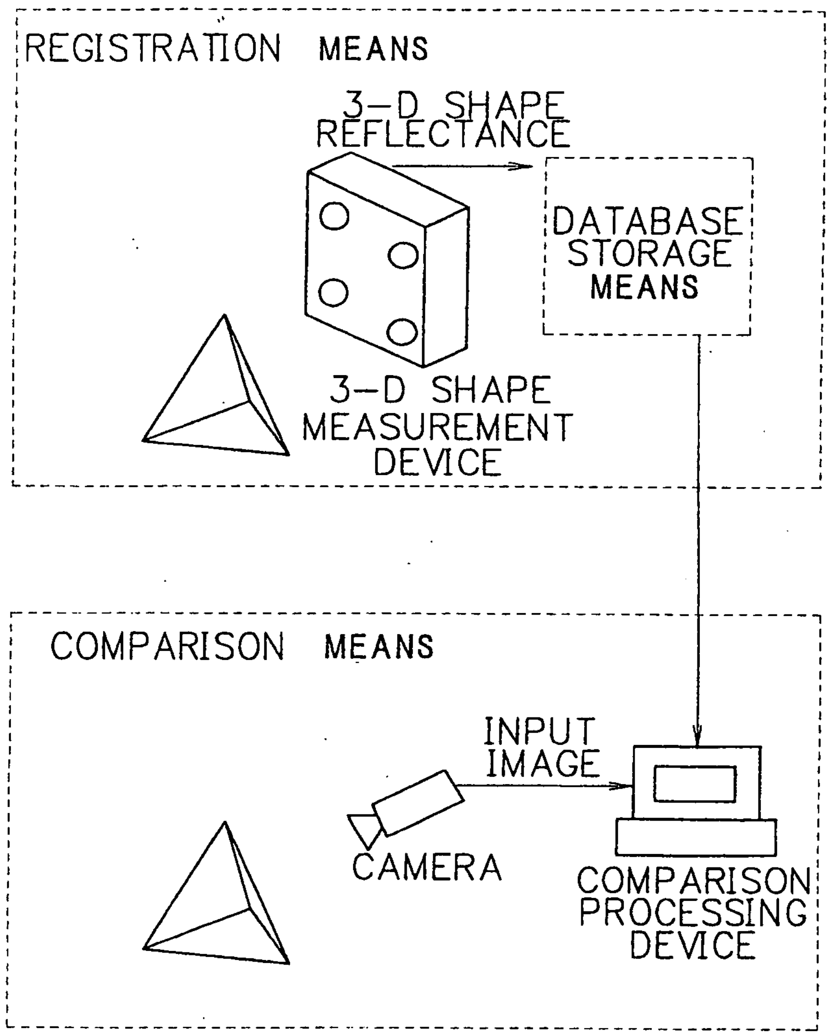

200
COMPARISON MEANS
PHOTOGRAPHING MEANS
210
INPUT IMAGE
POSITION/POSE ESTIMATION MEANS
220
POSITION/POSE
ILLUMINATION CORRECTION MEANS
230
REFERENCE IMAGE
IMAGE COMPARISON MEANS
240
EVALUATION VALUE
COMPARISON JUDGMENT MEANS
250
RESULT
REGISTRATION MEANS
3-D SHAPE MEASUREMENT MEANS
110
REFLECTANCE MEASUREMENT MEANS
120
3-D SHAPE
REFLECTANCE
DATA STORAGE MEANS
130
3-D SHAPE REFLECTANCE
100

FIG. 2



REGISTRATION MEANS
3-D SHAPE
REFLECTANCE
DATABASE
STORAGE
MEANS
3-D SHAPE
MEASUREMENT
DEVICE
COMPARISON MEANS
INPUT
IMAGE
CAMERA
COMPARISON
PROCESSING
DEVICE

FIG. 3

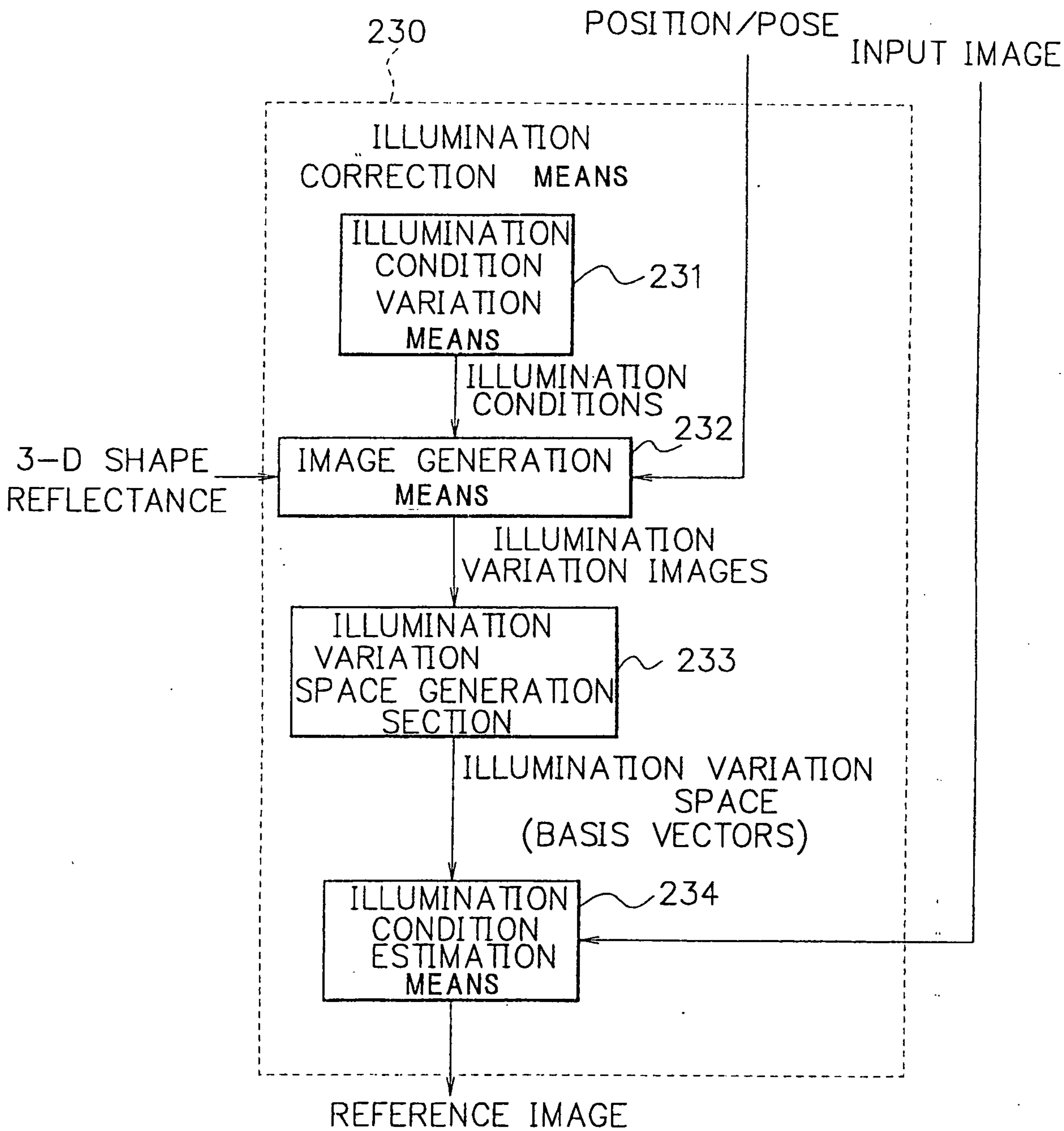

230
POSITION/POSE
INPUT IMAGE
ILLUMINATION CORRECTION MEANS
ILLUMINATION CONDITION VARIATION MEANS
231
ILLUMINATION CONDITIONS
232
3-D SHAPE REFLECTANCE
IMAGE GENERATION MEANS
ILLUMINATION VARIATION IMAGES
ILLUMINATION VARIATION SPACE GENERATION SECTION
233
ILLUMINATION VARIATION SPACE (BASIS VECTORS)
ILLUMINATION CONDITION ESTIMATION MEANS
234
REFERENCE IMAGE

FIG. 4

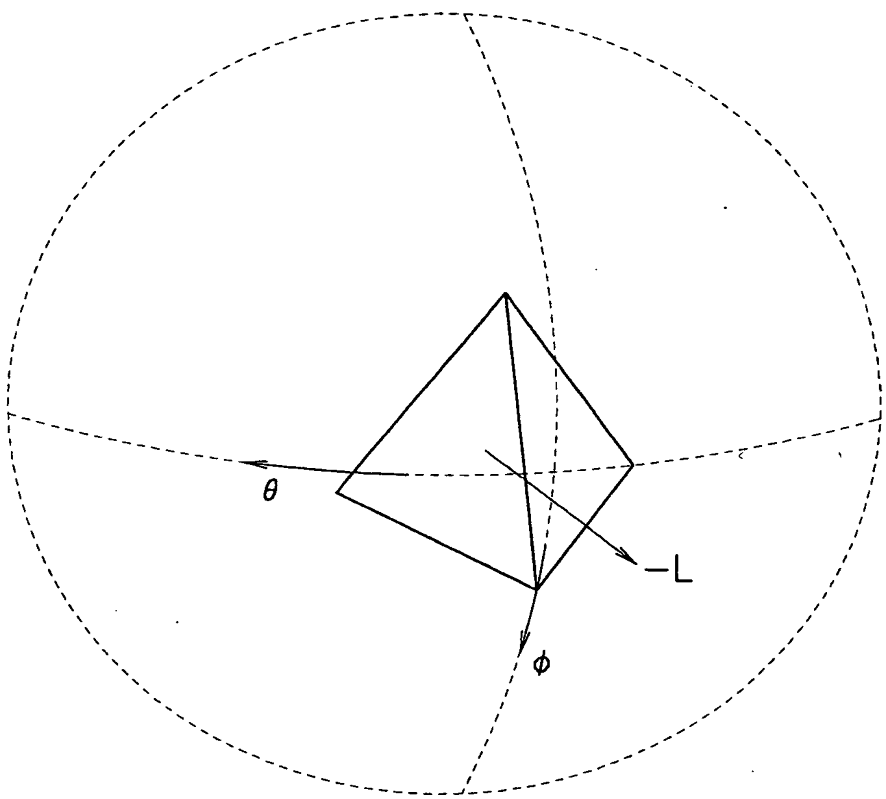


FIG. 5

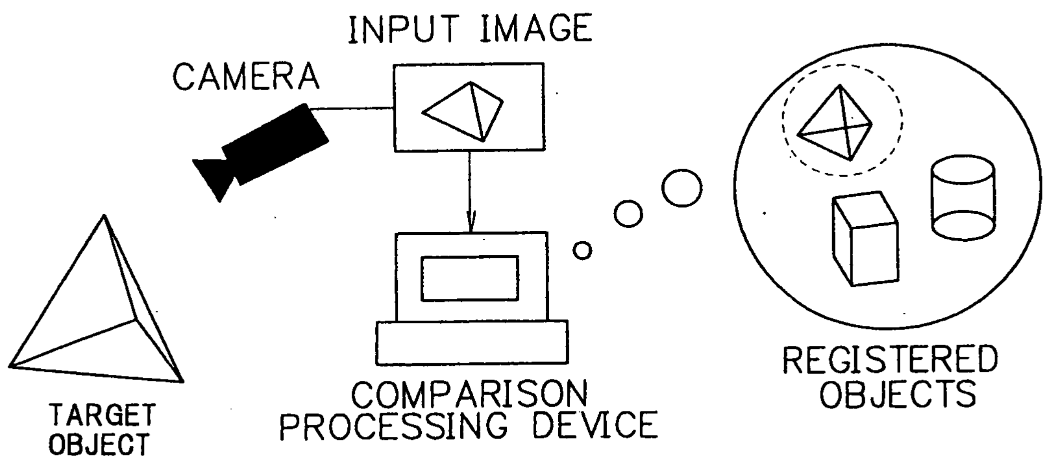
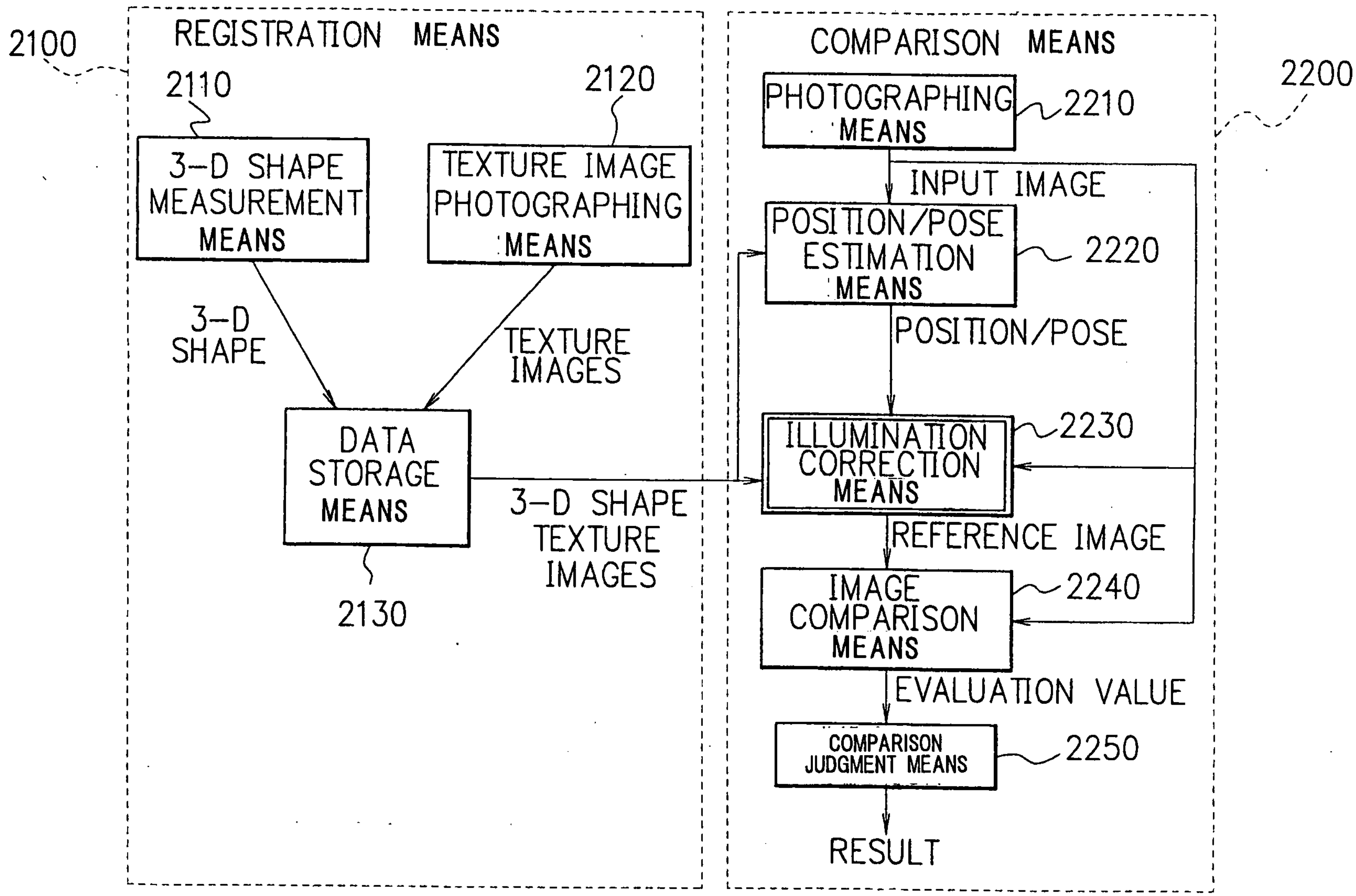
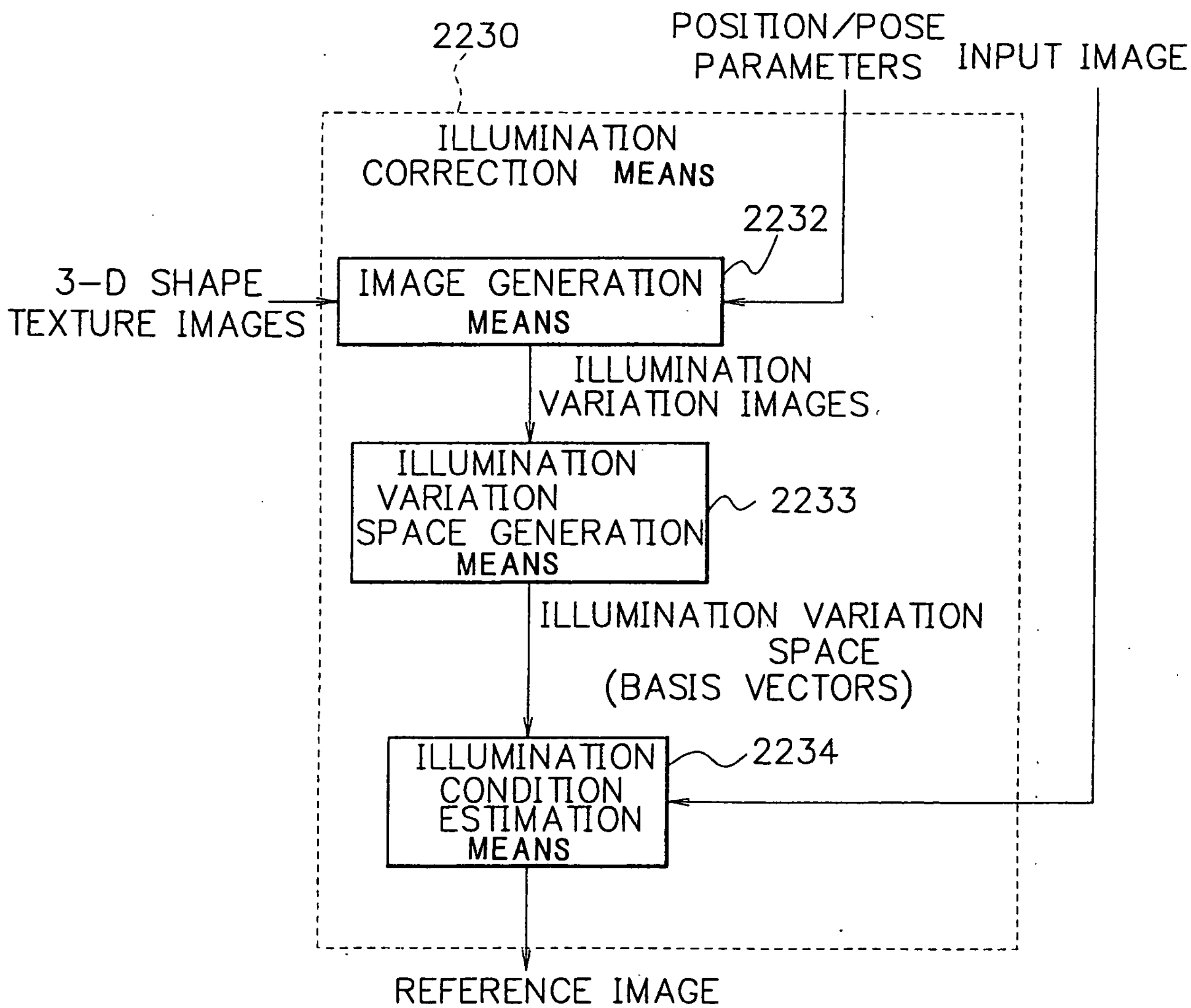

INPUT IMAGE
CAMERA
TARGET OBJECT
COMPARISON PROCESSING DEVICE
REGISTERED OBJECTS

FIG. 6



2100
REGISTRATION MEANS
2110
3-D SHAPE MEASUREMENT MEANS
2120
TEXTURE IMAGE PHOTOGRAPHING MEANS
3-D SHAPE
TEXTURE IMAGES
DATA STORAGE MEANS
2130
3-D SHAPE TEXTURE IMAGES
COMPARISON MEANS
2200
PHOTOGRAPHING MEANS
2210
INPUT IMAGE
POSITION/POSE ESTIMATION MEANS
2220
POSITION/POSE
ILLUMINATION CORRECTION MEANS
2230
REFERENCE IMAGE
IMAGE COMPARISON MEANS
2240
EVALUATION VALUE
COMPARISON JUDGMENT MEANS
2250
RESULT

FIG. 7



2230
POSITION/POSE PARAMETERS
INPUT IMAGE
ILLUMINATION CORRECTION MEANS
2232
3-D SHAPE
TEXTURE IMAGES
IMAGE GENERATION MEANS
ILLUMINATION VARIATION IMAGES
ILLUMINATION VARIATION SPACE GENERATION MEANS
2233
ILLUMINATION VARIATION SPACE (BASIS VECTORS)
ILLUMINATION CONDITION ESTIMATION MEANS
2234
REFERENCE IMAGE

FIG. 8

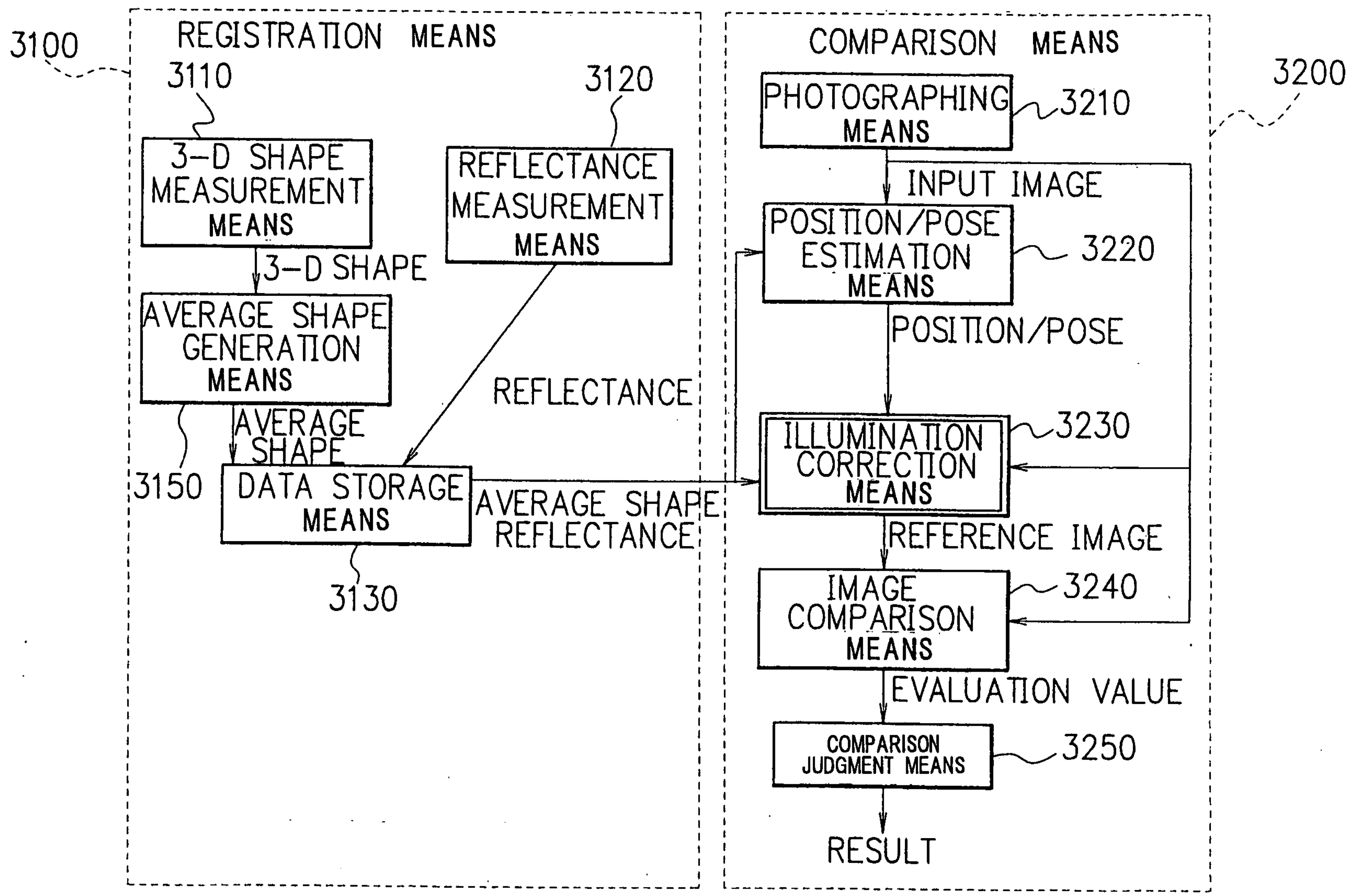
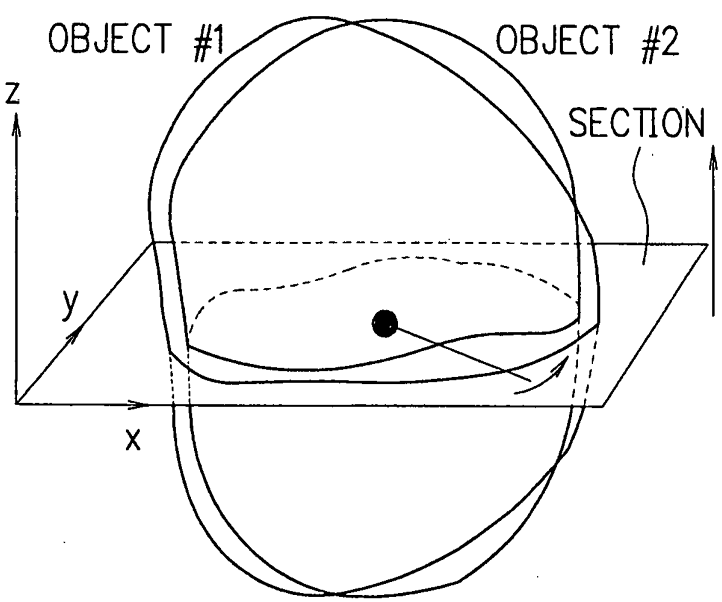
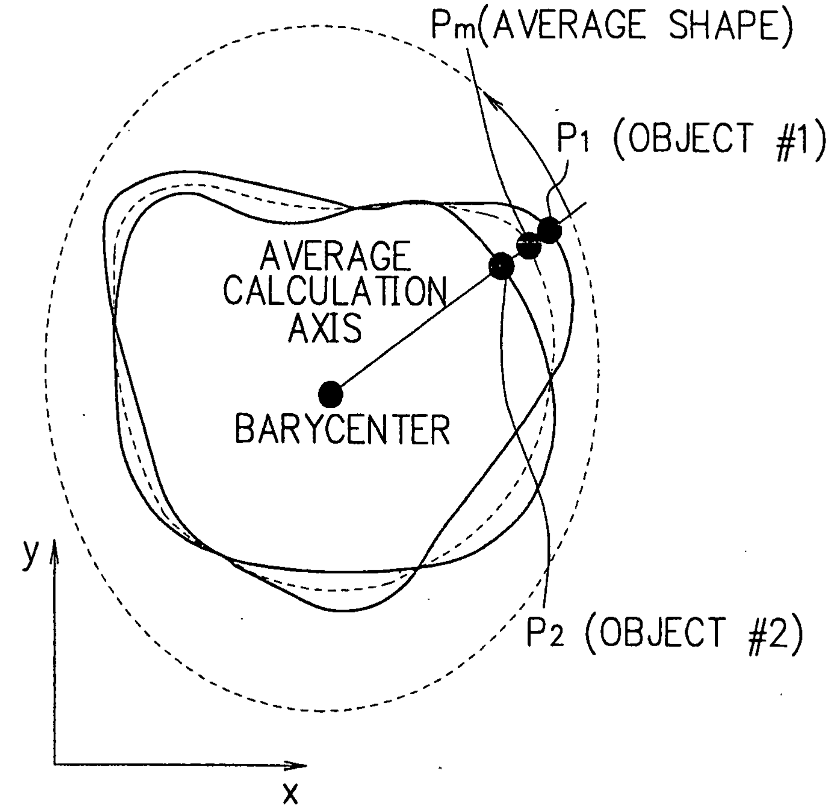

3100
REGISTRATION MEANS
3110
3-D SHAPE MEASUREMENT MEANS
3-D SHAPE
AVERAGE SHAPE GENERATION MEANS
3150
AVERAGE SHAPE
3120
REFLECTANCE MEASUREMENT MEANS
REFLECTANCE
DATA STORAGE MEANS
3130
AVERAGE SHAPE
REFLECTANCE
COMPARISON MEANS
3200
PHOTOGRAPHING MEANS
3210
INPUT IMAGE
POSITION/POSE ESTIMATION MEANS
3220
POSITION/POSE
ILLUMINATION CORRECTION MEANS
3230
REFERENCE IMAGE
IMAGE COMPARISON MEANS
3240
EVALUATION VALUE
COMPARISON JUDGMENT MEANS
3250
RESULT

FIG. 9


OBJECT #1
OBJECT #2
SECTION
z
y
x

(a)


Pm(AVERAGE SHAPE)
P1 (OBJECT #1)
AVERAGE CALCULATION AXIS
BARYCENTER
P2 (OBJECT #2)
y
x

(b)

FIG. 10

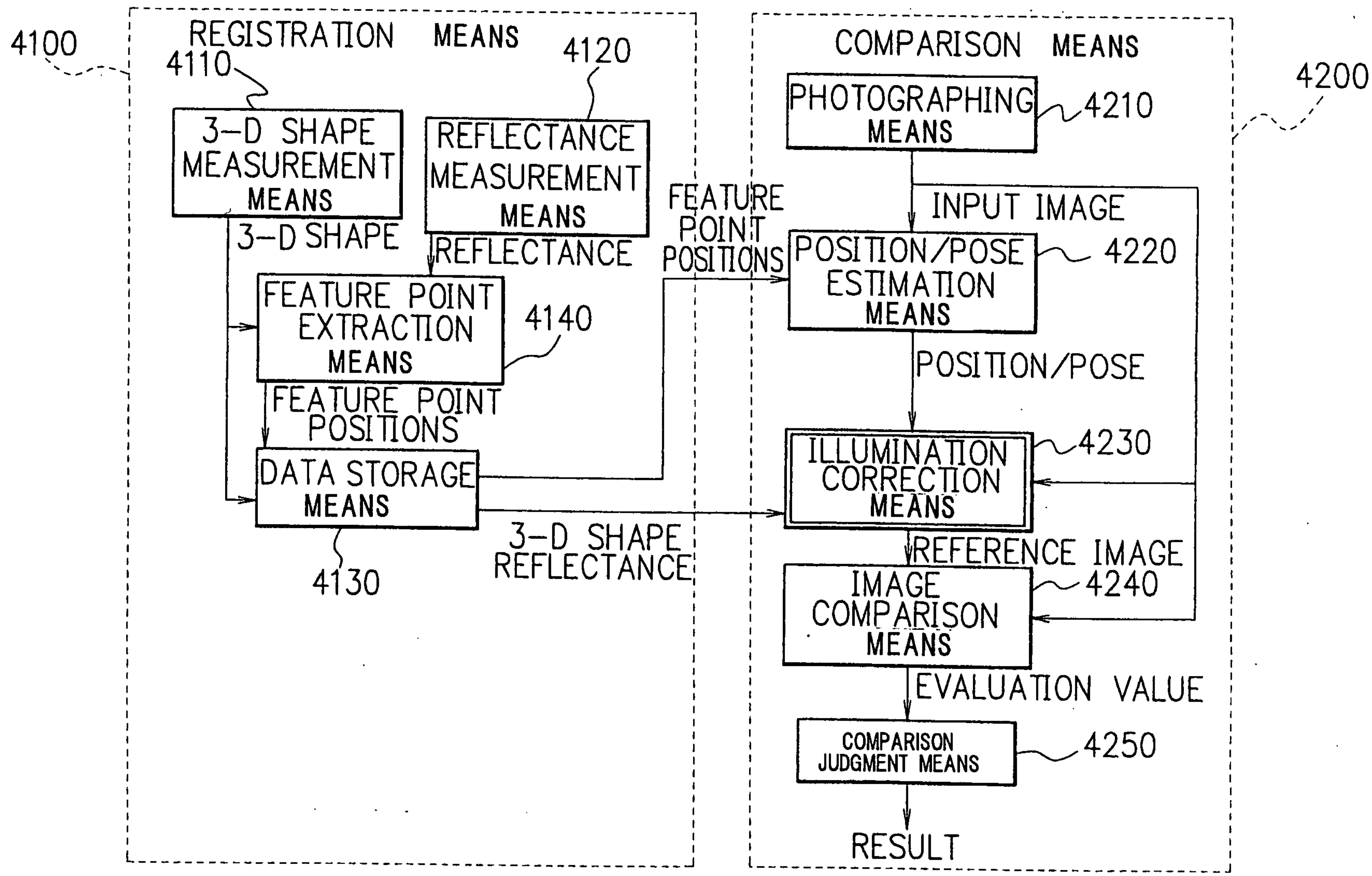

4100
REGISTRATION MEANS
4110
3-D SHAPE MEASUREMENT MEANS
4120
REFLECTANCE MEASUREMENT MEANS
3-D SHAPE
REFLECTANCE
FEATURE POINT EXTRACTION MEANS
4140
FEATURE POINT POSITIONS
DATA STORAGE MEANS
4130
3-D SHAPE REFLECTANCE
FEATURE POINT POSITIONS
COMPARISON MEANS
4200
PHOTOGRAPHING MEANS
4210
INPUT IMAGE
POSITION/POSE ESTIMATION MEANS
4220
POSITION/POSE
ILLUMINATION CORRECTION MEANS
4230
REFERENCE IMAGE
IMAGE COMPARISON MEANS
4240
EVALUATION VALUE
COMPARISON JUDGMENT MEANS
4250
RESULT

FIG. 11

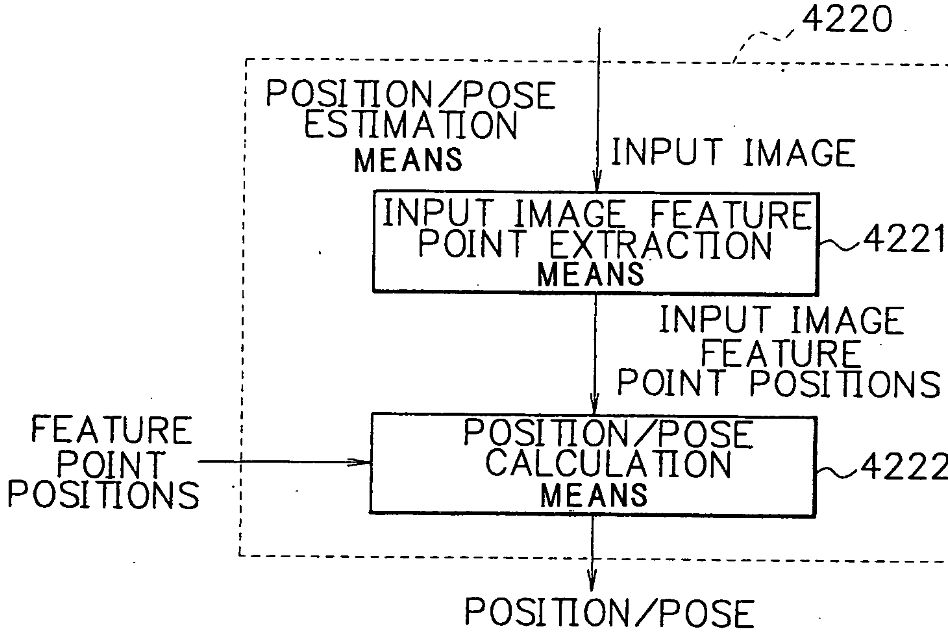

4220
POSITION/POSE ESTIMATION MEANS
INPUT IMAGE
INPUT IMAGE FEATURE POINT EXTRACTION MEANS
4221
INPUT IMAGE FEATURE POINT POSITIONS
FEATURE POINT POSITIONS
POSITION/POSE CALCULATION MEANS
4222
POSITION/POSE

FIG. 12

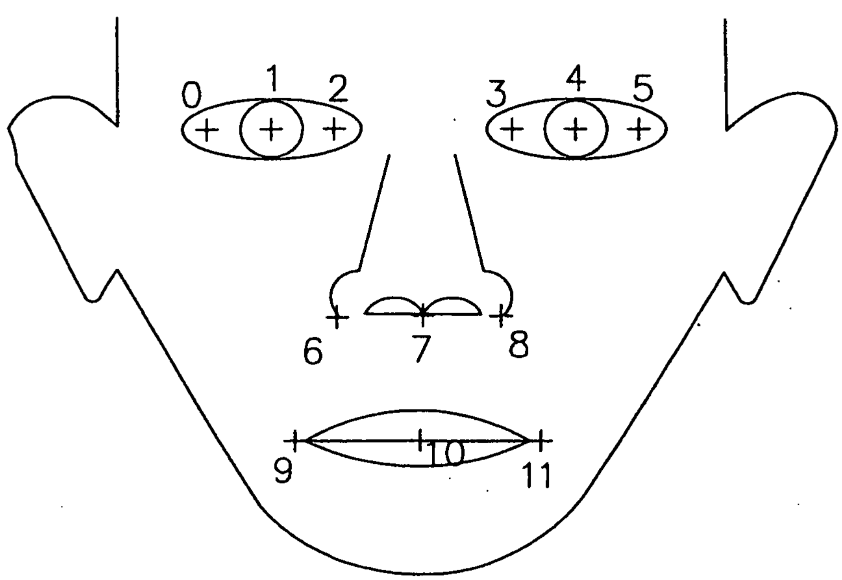

0
1
2
3
4
5
6
7
8
9
10
11

FIG. 13

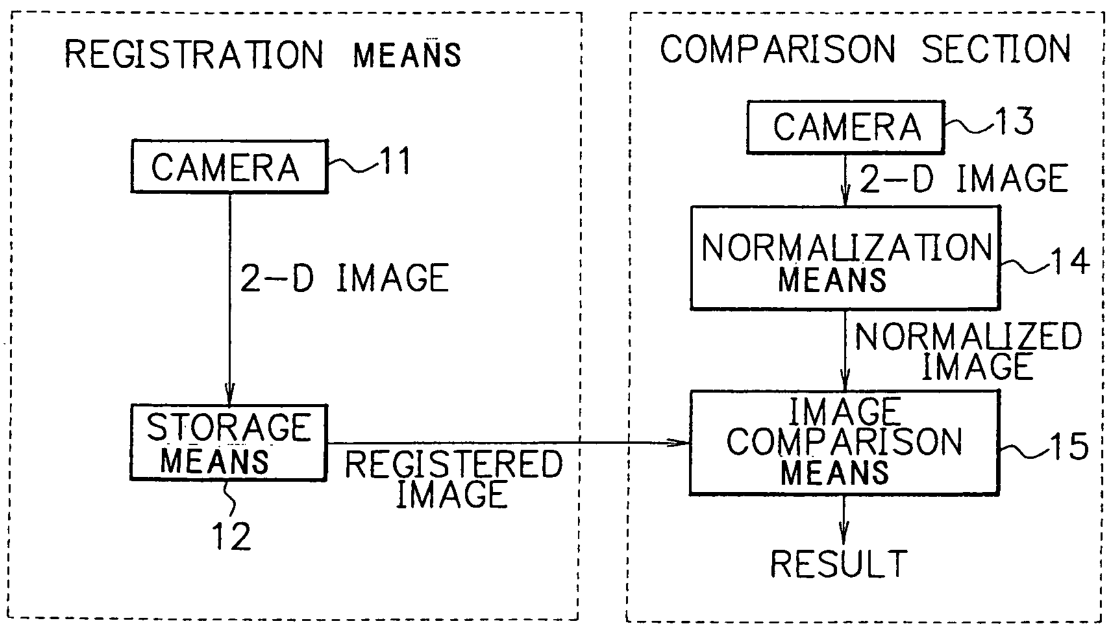

REGISTRATION MEANS
CAMERA
11
2-D IMAGE
STORAGE MEANS
12
REGISTERED IMAGE
COMPARISON SECTION
CAMERA
13
2-D IMAGE
NORMALIZATION MEANS
14
NORMALIZED IMAGE
IMAGE COMPARISON MEANS
15
RESULT

FIG. 14

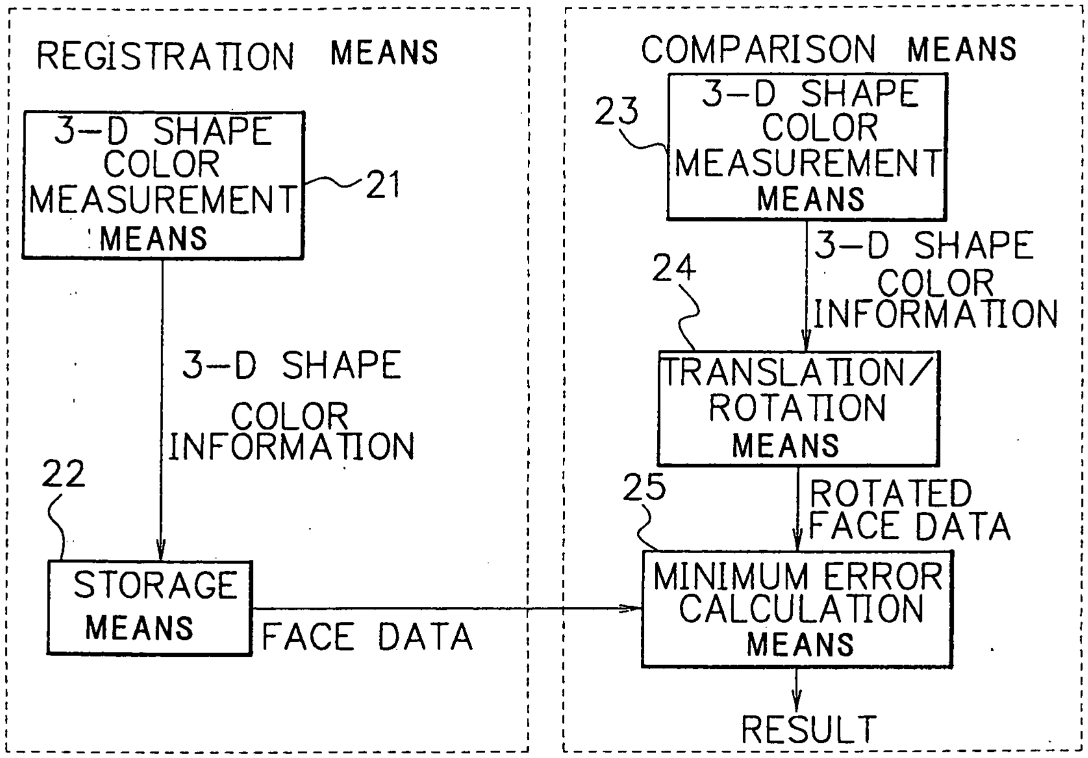

REGISTRATION MEANS
3-D SHAPE COLOR MEASUREMENT MEANS
21
3-D SHAPE COLOR INFORMATION
22
STORAGE MEANS
FACE DATA
COMPARISON MEANS
23
3-D SHAPE COLOR MEASUREMENT MEANS
3-D SHAPE COLOR INFORMATION
24
TRANSLATION/ROTATION MEANS
25
ROTATED FACE DATA
MINIMUM ERROR CALCULATION MEANS
RESULT

FIG. 15

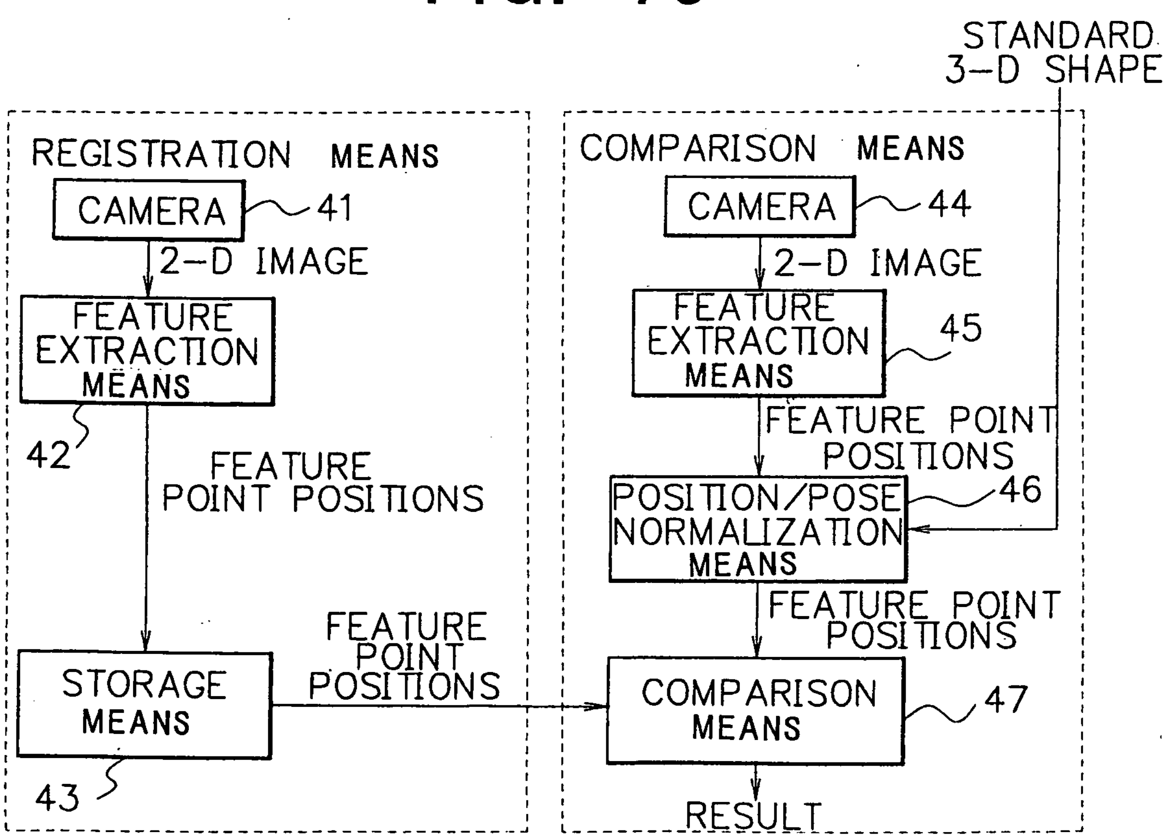

STANDARD 3-D SHAPE
REGISTRATION MEANS
CAMERA
41
2-D IMAGE
FEATURE EXTRACTION MEANS
42
FEATURE POINT POSITIONS
STORAGE MEANS
43
FEATURE POINT POSITIONS
COMPARISON MEANS
CAMERA
44
2-D IMAGE
FEATURE EXTRACTION MEANS
45
FEATURE POINT POSITIONS
POSITION/POSE NORMALIZATION MEANS
46
FEATURE POINT POSITIONS
COMPARISON MEANS
47
RESULT

FIG. 16

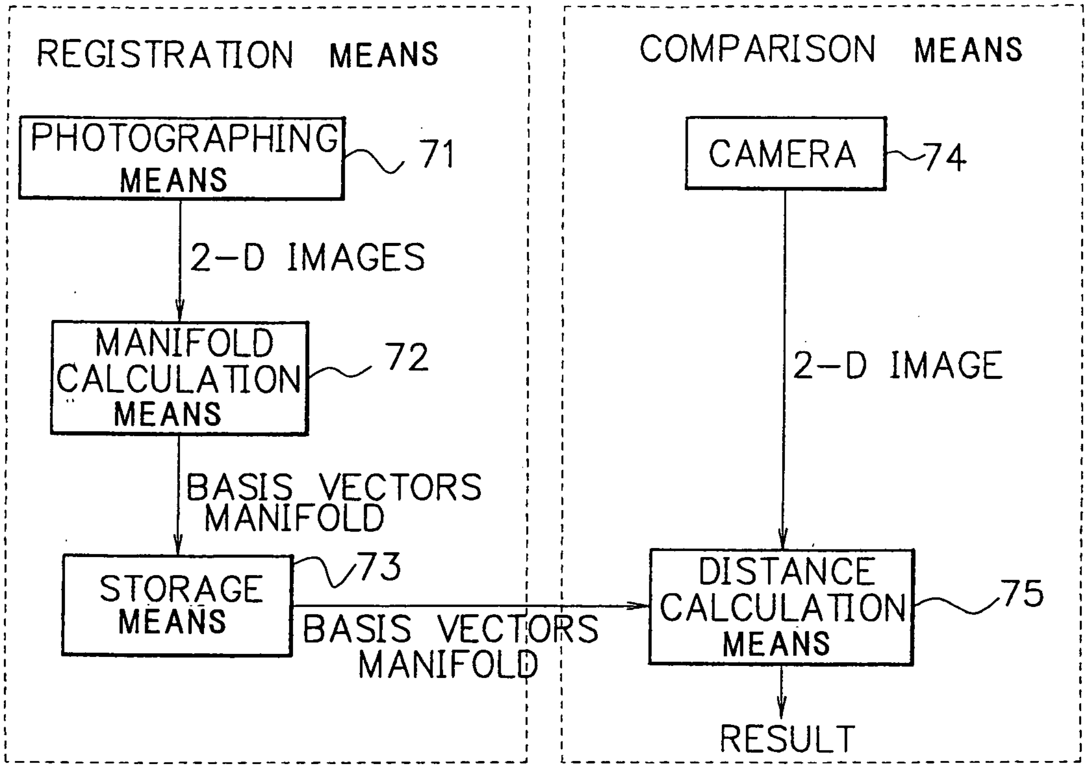
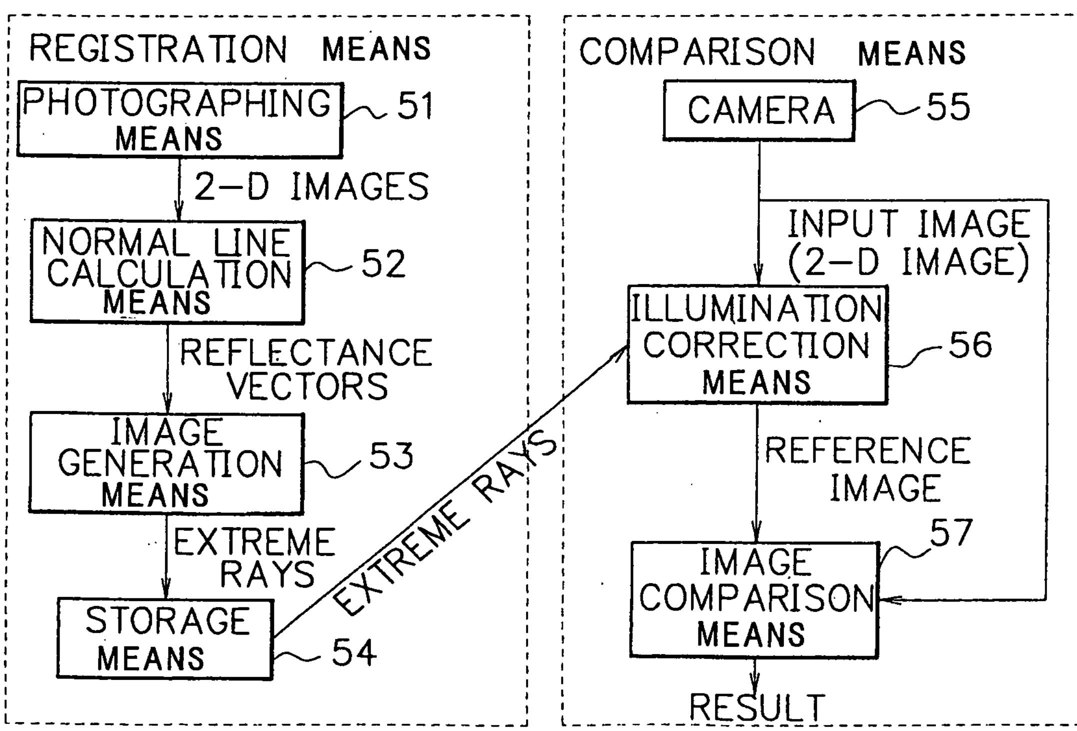

REGISTRATION MEANS
PHOTOGRAPHING MEANS
71
2-D IMAGES
MANIFOLD CALCULATION MEANS
72
BASIS VECTORS MANIFOLD
STORAGE MEANS
73
BASIS VECTORS MANIFOLD
COMPARISON MEANS
CAMERA
74
2-D IMAGE
DISTANCE CALCULATION MEANS
75
RESULT

FIG. 17


REGISTRATION MEANS
PHOTOGRAPHING MEANS
51
2-D IMAGES
NORMAL LINE CALCULATION MEANS
52
REFLECTANCE VECTORS
IMAGE GENERATION MEANS
53
EXTREME RAYS
STORAGE MEANS
54
EXTREME RAYS
COMPARISON MEANS
CAMERA
55
INPUT IMAGE (2-D IMAGE)
ILLUMINATION CORRECTION MEANS
56
REFERENCE IMAGE
57
IMAGE COMPARISON MEANS
RESULT